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DEVELOPMENT OF A SYSTEM TO PERFORM, RECORD, AND ANALYZE MEASUREMENTS OF RADON CONCENTRATIONS ON A LARGE SCALE

THESIS

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THESIS

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of the Air Force Institute of Technology

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Master of Science in Engineering Physics

William D. Pierce

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Preface

The purpose of this study was to develop the necessary procedures, protocols, and computer software to perform radon concentration measurements on a large scale. An integrated database system had to be set up to handle large amounts of data. As a trial run of the completed package, a preliminary survey of the radon concentrations in several buildings on Wright-Patterson AFB was taken.

I wish to extend my sincerest gratitude to Dr. George John, whose assistance, advice, pressure, and knowledge of the English language was invaluable. I would also like to acknowledge the help of the technicians of the Engineering Physics Department in acquiring the necessary software and equipment I needed, especially Bob Hendricks and Leroy Cannon. Thanks also to the many building monitors who interrupted their busy schedules to lead me through their respective buildings twice, and to Gary Lindsey and Mark Mays of Environmental Management.

Finally, I wish to express appreciation for my loving parents, who were always there when I needed support and my girlfriend Andrea, who is anxiously waiting for me to come home.

William David Pierce

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Abstract

A system to process large numbers of radon samples of buildings on Wright-Patterson AFB was developed. The method for measuring the radon concentrations indoors had been developed previously by AFIT students; however, an integrated system was required to not only collect data but save and access data as well. A survey form based on the EPA's national radon survey form was designed and used to gather information on each building, including possible radon sources and methods of distribution. A large database was set up to facilitate storage of the information collected. Several programs were written to handle input, manipulation, analysis, and output of the data. A general user's manual was written to explain how the entire system and each program may be used.

Some base buildings were tested and evaluated for indoor radon concentrations, in order to demonstrate the operation of the system. Most buildings tested had radon concentrations below the EPA's action radon concentration. The system operates well, and is ready for certification by the EPA.

DEVELOPMENT OF A SYSTEM TO PERFORM
RADON CONCENTRATION MEASUREMENTS
ON A LARGE SCALE

I. Introduction

The health risk attributable to radon gas in buildings has received great attention in the last few years. Recent evidence shows that about 55% of the radiation dose to the respiratory tract in humans is due to this unseen gas, and estimates of the risks attributable to radon range up to 25% of all lung cancers in the US (1). Because of the enormity of the perceived health risk, much research has been devoted to the development of cheap but accurate detectors for household measurements of radon concentrations.

George John and several students at the Air Force Institute of Technology have been working on this problem since 1984, and have tested two separate systems. The first to be developed was based on a charcoal-filled canister designed by Cohen at the University of Pittsburgh (2), and built at AFIT by Gill. The radon adsorbed by the charcoal in these canisters was measured by detection of the gamma rays emitted by the radon's progeny as they decay. The second system also was based on charcoal adsorption, but the containers are plastic vials built by Packard. The radon in the charcoal is measured by liquid scintillation counting of the alpha and beta particles emitted.

The object of this research project was to develop the procedures and protocols necessary to use the second system for large-scale testing, recording, and analysis of radon concentrations in houses and government buildings. Several items had to be developed or perfected, including survey forms, vial handling procedures, an integrated database system, and user-manuals so someone new to the project could perform testing without elaborate training. In addition, the system was tested by performing a preliminary survey of some buildings on Wright-Patterscn AFB.

Survey forms have been designed to collect information on the type of building structure; especially those issues relevant to sources and dispersion of radon gas. A substantial database system has been designed to record and access the data accumulated by the survey forms. Several computer programs were written to facilitate the input, analysis, and output of the data collected both by the survey forms and the radon detectors.

The vial analysis protocol had been developed by Sharp, but an entire system of vial handling procedures had to be completed. A series of vials were run in the radon chamber available in building 470, to determine how to handle the vials from procurement to disposal. Minor improvements and clarifications were also made to Sharp's protocol.

An integrated database, using the commercial software package dBase III Plus, was developed to store the results from both the survey forms and the radon testing. Several programs and procedures had to be developed to perform the basic functions required, including data input and retrieval, calculation of radon concentrations from count rates, and routine maintenance of the database.

User-manuals were written so that someone unfamiliar with the use of radon detectors could perform testing of buildings. The two main manuals were written for using the database and following the protocols in handling the vials. In addition, some guidelines for filling out the survey forms and distributing the vials properly have been included.

A preliminary survey of the radon concentrations in a number of buildings on Wright-Patterson Air Force Base was taken after the necessary programs and protocols were developed. The survey served as a trial run of the entire system, and the results were reported both to the building monitors and to the Environmental Management Office.

Originally, the intention was to have the entire system certified by the EPA. Unfortunately, the EPA was re-evaluating their certification process, and they were not ready to proceed until after this project was finished. However, the system has been completely set up and is ready to undergo whatever testing the EPA requires.

Chapter II of this paper describes background information on radon gas and various methods for detection. Chapter III provides a description of the development of the integrated database and its software. Chapter IV describes the results of the experimental parts of the project. Chapter V contains concluding remarks and suggested items for future study. Finally, the five appendices contain the results of the base survey, a copy of the survey form, a user's guide for the integrated database, a recipe for using the radon vials, and the programs developed for the database.

II. Background

This chapter contains background information necessary for the reader to understand the basic principles underlying the detection and measurement of radon concentrations in air. The first section describes the three isotopes of radon gas, and why ^{222}Rn is the common target of detection schemes. The second section explains the decay of radon and its progeny. The third section describes the health hazard and provides some methods of calculating lung cancer risk from known concentrations of radon. The fourth section discusses commonly used detection and measurement techniques. The fifth section relates the development of radon detectors at AFIT, including the selection of liquid scintillation vials for the detection system used in this project. The sixth section discusses liquid scintillation (LS) counting, and the specific equipment used here to implement LS counting. Finally, the chapter concludes with the development of a protocol to process LS vials. Any uncited data in Chapter II is taken from (3), as that book by the EPA is designed to provide an overview of the instrumentation available for the measurement of radon and its progeny.

Radon Gas

Radon is an invisible, odorless gas which is heavier than air. Although it is generally assumed to be an inert gas, in actuality it is a "metalloid" -- it lies on the diagonal of the Periodic Table between the true metals and nonmetals. It therefore demonstrates some of the properties of both. Stein and some other researchers (4) have demonstrated that radon will form a difluoride and several complex salts, but in air it is generally considered to be unreactive. Radon's atomic number, 86, places it in the noble gas column and for this investigation it will be assumed inert.

There are three known isotopes of radon, ^{219}Rn, ^{220}Rn, and ^{222}Rn. All are radioactive, but each belongs to a different radionuclide series. Both ^{219}Rn and ^{220}Rn have short half-lives of less than one minute, whereas the half-life of ^{222}Rn is about 3.8 days. It takes time for radon gas to diffuse out of soil and enter living spaces, so the major contributor to doses to the general public is ^{222}Rn.

Actinon (^{219}Rn) is a member of the ^{235}U-Actinium series. Since ^{235}U comprises less than one percent of all uranium found naturally on the earth, ^{219}Rn is relatively rare, in fact it is the least abundant of the three radon isotopes. It has a short half-life of only about 4 seconds, and so is difficult to measure in the atmosphere. Because of its short half-life, almost all atoms of this isotope of radon decay before they can diffuse out of the soil.

Thoron (^{220}Rn) is a member of the ^{232}Th series. The ^{232}Th series and the ^{238}U series, parent of ^{222}Rn, are considered to have about the same overall global activity. However, ^{220}Rn's short half-life of 55.6 seconds means that there is a high radioactive flux out of the earth's surface of about 1.7 Bq/m^2-s (40 pCi/m^2-s) (5) from ^{220}Rn alone, the highest flux of any of the three isotopes of radon by 2 orders of magnitude. Still, because of ^{220}Rn's short half-life and the slow diffusion rate of radon out of soil and rocks (discussed below), it does not have sufficient time to distribute itself to become as much of a health hazard as ^{222}Rn. One of the progeny of ^{220}Rn, ^{212}Pb (half-life of 10.6 hours), is a health risk however, because it contributes to the total natural radiation exposure in some areas with high soil thorium concentrations and in uranium mines. The isotope ^{220}Rn is difficult to detect due to its short half-life, and since it poses less of a hazard to the public, radon detection programs focus on ^{222}Rn. Measurement of ^{220}Rn has been accomplished by measuring concentrations of both ^{220}Rn and ^{222}Rn , then passing the air through a chamber for 160 seconds (3.5 half-lives of ^{220}Rn), and then measuring the ^{222}Rn. This method, however, is complicated and expensive.

The subject of most detection schemes, ^{222}Rn, belongs to the ^{238}U series. While a typical flux from soil is about 17

mBq/m^2-s (0.45 pCi/m^2-s), only about one percent of the ^{220}Rn flux, its longer half-life of 3.82 days allows it to escape from the ground and accumulate in enclosed spaces. The longer half-life also means that it is fairly easy to take a sample of air, bring it back to the laboratory and measure the ^{222}Rn concentration present. This method is quite impossible for the other two isotopes of radon. For the remainder of this paper, ^{222}Rn will be referred to simply as "radon".

Radon is formed when ^{226}Ra decays by alpha particle emission. The amount of radon released into the atmosphere depends upon local soil conditions and local radium concentrations. Typical concentrations of ^{226}Ra in soil are about 40 Bq/kg, but can be slightly higher for concrete and bricks.

When a ^{226}Ra atom decays, most of the 4.87-MeV decay energy released is carried off by the recoiling alpha particle. The progeny ^{222}Rn nucleus has only about 100 keV available for recoil. With that energy, its range in air is about 65 μm, but in typical minerals only 20-70 nm. In order to be released into the air, it must stop in the pore spaces of the mineral or soil from which it was released. If it retains too much energy, it may embed itself into the mineral on the opposite side of the pore. Moisture in the pore spaces may stop a recoiling radon atom before it embeds itself in the opposite side of the pore as it would in dry soil, since the range of a radon atom with 100 kev of energy is only about 100 nm in water. Through this mechanism, the release of radon gas into the pores is greatly enhanced in moist soil. However, the radon atom must still escape from the wet pore space into the atmosphere. If the soil is too moist, the radon may not escape, since the diffusion rate of radon gas through air is much higher than through water. Strong and Levins measured the emanation rate of radon gas from columns of uranium mill tailings with three different moisture contents, dry, moist, and saturated. The flux rate of radon gas from the moist column was 3.5 times that from the dry column, and 54 times that from the saturated column. The moist column had a water content of about 5.7% by weight, a typical value for soil.

Decay of Radon

Radon decays into radioactive progeny that emit alpha, beta, and gamma radiation, summarized in Table 1. First, the ^{222}Rn atom, with a half-life of 3.824 days, decays by alpha emission into ^{218}Po, releasing 5.49 MeV of decay energy. The progeny ^{218}Po has a half-life of 3.05 minutes, and emits an alpha particle with an energy of 6.00 MeV. The resulting ^{214}Pb has a half-life of 26.8 minutes. It decays by consecutive beta emissions (and coincident gamma rays) first into ^{214}Bi, with a half-life of 19.7 minutes, and then into ^{214}Po. Finally, ^{214}Po decays almost immediately (half-life only 163.7 microseconds) by alpha emission into ^{210}Pb, releasing 7.69 MeV.

Since ^{210}Pb has a half-life of 22 years, the chain of events is effectively ended.

The four progeny between radon and ^{210}Pb have much shorter half-lives than the parent radon, so after about four hours

Table 1. Decay of Radon and Its Progeny

^{222}Rn Decay Energies and Percentages							
Nuclide	Half-life	α-particles		β-particles		γ-rays	
		MeV	%	MeV	%	MeV	%
^{222}Rn	3.824 d	5.49	100	-	-	-	-
^{218}Po	3.05 min	6.00	100	-	-	-	-
^{214}Pb	26.8 min	-	-	0.65 0.71 0.98	50 40 6	0.295 0.352	19 36
^{214}Bi	19.7 min	-	-	1.00 1.51 3.26	23 40 19	0.609 1.120 1.764	47 17 17
^{214}Po	163.7 μs	7.69	100	-	-	-	-

they reach secular equilibrium with the parent. In that state the rate of radioactive emissions of each product is essentially equal to that of the parent. Any one or all of the decay events then is an accurate measure of the actual radon concentration itself.

The major health hazard to humans is not from the radiation released by the decay of radon itself, but from the emissions of its progeny. When a radon atom decays, the first decay product created is ^{218}Po. As the alpha particle is ejected from the nucleus, it rips away with it not only an equal charge in electrons, but also some of the other weakly bound orbital electrons. Thus the ^{218}Po atom, just after the decay event, is a positively charged ion.

Almost immediately the charge is neutralized by recombination. In the atmosphere, the ^{218}Po atom then forms a cluster, adsorbing water molecules and various trace gases. In addition, polonium may form simple compounds with oxygen, or substances such as nitrate or sulphate. The ambient aerosols in the atmosphere attach to the cluster around the ^{218}Po atom fairly quickly (on the order of 100 seconds in open atmosphere). This is a continual process, and radon is constantly being released into the air and decaying. There is always a fraction of the ^{218}Po unattached to the ambient aerosol, but most of it is attached. It is conventional in the literature to refer to the "attached" and "unattached" progeny of radon.

The subsequent decay of ^{218}Po by alpha emission into ^{214}Pb releases enough energy for the ^{214}Pb to become unattached. The history of a lead ion in the atmosphere is similar to that of a polonium ion; including recombination, adsorption, and clustering. There is generally, though, only about 1/10 as much unattached ^{214}Pb as unattached ^{218}Po in the atmosphere.

Since beta particles have such small mass compared with alpha particles, they cannot impart nearly as much recoil energy to the atom as it decays. The progeny ^{214}Pb and ^{214}Bi decay by beta emission, so insufficient energy for detachment of their products is released. The alpha emission from ^{214}Po into ^{210}Pb does provide sufficient recoil energy for detachment of the lead, but the long half-life of ^{210}Pb implies that its health hazard is negligible compared with its parents.

There are several ways for the radioactivity from radon to enter the body; direct entrance through the skin, drinking water containing radon, and breathing airborne radon. Decay in the atmosphere allows alpha, beta, and gamma radiation to enter the skin directly. This is probably the least important mechanism. Alpha and beta particles travel only short distances through air (alphas about 5 cm, betas about 1 m), and since radon does not attach to the skin, most of their energy is dissipated into the air. U. S. water supplies contain dissolved radon gas; most have under 2000 pCi/l. This may seem like a large amount, however, the danger is not from drinking the water. When water is heated, the diffusion rate out of the water is greatly increased. Forcing the water into small droplets increases its surface area dramatically, so showering allows the radon to add to the concentration in indoor air. It is estimated that 10,000 pCi/l in the drinking water of a typical household adds about 1 pCi/l to the indoor air concentration.

The chief health hazard from radon gas is from deposition of radon progeny onto the bronchial epithelium. Radon gas itself does not readily deposit onto surfaces, so it is exhaled with the air. Attached progeny also are generally exhaled, or are swept up by cilia and olfactory hair in the upper respiratory tract. The unattached progeny penetrate further into the respiratory system, since they are much smaller particles than the attached progeny. Once deep into the trachea and bronchi, these small, reactive particles deposit onto surfaces quite efficiently, including the epithelium of the respiratory tract. Once attached to the epithelium, any subsequent energy given off by radioactive decay is almost totally absorbed by the surrounding tissue. The decays of ^{218}Po and ^{214}Po cause the most harm for two reasons. First, they give off the most energy of the decay chain. Second, and more importantly, since they emit alpha particles, the stopping power of the tissue is very high, so that all the energy is absorbed in a very short distance. It appears that the greatest risk is to the basal cells found 20-90 μm below the surface of the epithelium.

The unattached progeny of radon have such small size (2-20 nm) that their diffusion rates through air are high. Recent experiments have shown typical rates for unattached progeny to be between 0.0025 and 0.07 cm^2/s (Frey et al, 1981, as cited in 2). These relatively high diffusion rates imply that the unattached progeny quickly disperse and distribute themselves. More importantly for health considerations, they also deposit themselves in the bronchial tree quite efficiently. There is, therefore, a much higher dose given to the bronchi from the unattached ^{218}Po in the atmosphere than from the equally radioactive attached ^{218}Po, even though the attached concentration is an order of magnitude greater. The NCRP (1984) estimated the dose rate to the bronchial epithelium from radon gas in the following equation:

$$\text{Dose (mrad/yr)} = 980\ [\text{unattached RaA}] + 29\ [\text{RaA}] + 160\ [\text{RaB}] + 140\ [\text{RaC}]; \tag{1}$$

where the brackets represent concentrations in pCi/l, and RaX is the old designator for the progeny of radium (RaA is ^{218}Po, RaB is ^{214}Pb, and RaC is ^{214}Bi). (6) In radioactive equilibrium, all three concentrations would be about equal, so roughly three quarters of the dose rate is from the unattached portion of ^{218}Po.

Lung Cancer Risk from Radon

The overall risk of developing lung cancer because of exposure to a known concentration of radon gas is calculated from the Working Level (WL). The hazard is related to the total amount of energy deposited in the lung tissue by the alpha decays of ^{218}Po and ^{214}Bi. One WL is defined as the concentration of radon progeny per liter of air that results in the emission of 1.3×10^5 MeV of alpha particle energy after all progeny have decayed into lead. If the concentrations of the various radon progeny in the air are given in pCi/l, Eq (2) gives the overall working level, calculated from the individual concentrations.

$$WL = 0.00105\,[^{218}Po] + 0.00516\,[^{214}Pb] + 0.00379\,[^{214}Bi] \tag{2}$$

Note: These coefficients seem counterintuitive. One must keep in mind that the half-life of ^{214}Pb is longer than the half-life of ^{218}Po or ^{214}Bi, so that an equal concentration in pCi/l implies a larger number of atoms per unit volume.

Equation (2) defines 1 WL as the exposure from 100 pCi/l each of radon and its progeny, when they are all in secular equilibrium. Secular equilibrium is not the general case. Undisturbed air takes about four hours to reach secular equilibrium and normally radon is being added to the system constantly.

The Working Level Month (WLM) is a cumulative measure of exposure to radon progeny of 1 WL for one working month, i. e. 170 hours (ICRP uses 160 hours). According to this definition, the exposure in WLM is given in Eq (3):

$$WLM = \frac{WL \times Exposure\ time\ (hours)}{170} \quad (3)$$

According to the NCRP, the dose equivalent from a cumulative exposure of one WLM depends upon gender and age. One WLM is accepted by the NCRP as being 14.2 rem (0.71 rad) for an adult male, 12.6 rem (0.63 rad) for an adult female, and about 25 rem (1.25 rad) for a child. The WLM is an important measure of risk because the body repairs damage from radiation over time; so one exposure of ten WLM in a single year is much more hazardous than ten exposures of one WLM over ten years. The dependence of risk on exposure rate has led to defining the exposure rate in WLM/year when appropriate.

There are several different ways of estimating the risk of developing lung cancer from the WLM. The following three, from different sources, were not calculated from the predicted dose to the bronchial epithelium; instead they are based upon epidemiological studies of uranium miners. The risks are uncertain for two reasons: first, the miners generally received much larger doses than those expected for the general population, and the results are being extrapolated down. Second, other risk factors such as smoking and exposure at home have been ignored for all but one small group of the miners. In addition, since almost all miners involved were men, no evidence of risk to women or children is provided.

The first estimation of lung cancer risk from exposure to radon gas, in Table 2, is from the National Committee on Radiation Protection (NCRP).

Table 2. NCRP Lung Cancer Risk Coefficients

Annual lung cancer risk	1×10^{-5}/WLM
Lifetime lung cancer risk	1.5×10^{-4}/WLM
Lifetime lung cancer risk	1×10^{-2}/WLM per year

BEIR IV (Committee on Biological Effects of Ionizing Radiation, 1987) developed a modified relative risk model based on the fact that the risk varies based upon the age of the person exposed. The formula they developed is given as equation (4). Three observations may be made about this

$$r(a) = r_0(a)[1 + 0.025\gamma(a)(W_1 + 0.5 \times W_2)]$$

where;

$r_0(a)$ = *baseline lung cancer mortality rate at age a*
$\gamma(a)$ = 1.2 *for* $a<55$
= 1.0 *for* $55<a<64$
= 0.4 *for* $a>64$
W_1 = *cumulative exposure* (*WLM*) 5 → 15 *years before age a*
W_2 = *cumulative exposure* (*WLM*) >15 *years before age a*

(4)

method. First, relative risk decreases with age. The risk from the dose acquired 5-15 years before age a is twice as great as that from 15 years before. Finally, doses accumulated during the previous five years are neglected, as a 5 year latent period is assumed. It is possible to generalize and derive the following coefficients, shown in Table 3. These are approximately twice the NCRP's estimates.

Table 3. BEIR IV Lung Cancer Risk Coefficients

Lifetime lung cancer risk	3.5×10^{-4} / WLM
Lifetime lung cancer risk	2.3×10^{-2} / WLM per year

The EPA uses a model similar to BEIR IV, with the coefficients shown in Table 4. The EPA's estimates are about

Table 4. EPA Lung Cancer Risk Coefficients

Lifetime lung cancer risk	5×10^{-4} / WLM
Lifetime lung cancer risk	1.5×10^{-2} / WLM per year

three times those of NCRP. The EPA has set an action level of 4 pCi/l of radon in areas occupied 75% of the time.

As an example, suppose an adult male lives for twenty years in an area where the radon concentration averages 4 pCi/l over the year. Normally, the amount of potential alpha energy from a known concentration of radon is only about half of the total of all possible decays, since secular equilibrium is not the norm. Then the exposure to that person's lungs would be about $0.04 \times 0.5 \times 20 \times 365.25 \times 24 / 170 = 20.63$

WLM. His lifetime risk of lung cancer would be 0.3% (NCRP), 0.7% (BEIR IV), or 1.0% (EPA). For comparison, if he was exposed to 20 WLM in a single year, the lifetime risk of lung cancer would be 20% (NCRP), 46% (BEIR IV), or 30% (EPA). The EPA estimates that overall, between 5,000 and 20,000 Americans die of lung cancer because of radon exposure every year.

Detection and Measurement of Radon Concentrations

Several different methods of determining radon concentrations in air have been developed. The most common of these methods are ionization chambers, scintillation cells, nuclear track detectors, electrostatic collectors, and charcoal adsorption. The US EPA has developed protocols for using all of these systems for radon concentration surveys (7). They all can be divided into three main groups, depending on the type of measurement: instantaneous, continuous (real-time), and time-averaging methods. These various methods can be further divided into passive or active collection techniques. Passive monitors depend on diffusion of the radon gas into the detector, while active monitors pull radon out of the air. Real-time passive monitors allow radon to diffuse in at a constant rate, and the radioactivity is measured over short time periods. They are valuable for assaying varying radon concentrations, usually on an hourly basis. Time-integrating passive detectors attempt to average the radon concentrations over longer periods.

Ionization chambers are large metal containers, generally in the shape of a cylinder with a coaxial wire to which a high voltage is applied. Radiation that deposits its energy inside creates ion pairs in the chamber's gas. The resulting charge is collected by the anode and cathode and recorded as a pulse. The air to be tested is filtered to remove aerosols (including radon progeny) before entering the sensitive volume. Although ionizacion chambers can be both accurate and very sensitive (detection limits as low as 0.1 pCi/l have been reported), they are normally only used in research where few samples are to be taken, since cheaper devices have become available.

Scintillation cells are closed vessels coated on the inside with ZnS(Ag), zinc sulfide activated with silver. ZnS(Ag) is an opaque white powder which emits light (wavelength 450 nm) when struck by alpha radiation. Photo-multiplier tubes (PMT's) are used to collect the light. Scintillation cells are unsuitable for spectral analysis, but are essentially insensitive to any background radiation except for alpha particles. Lucas developed probably the most important of the scintillation counters (8). His version is a long metal cylinder utilizing a quartz window to allow the light to escape to a PMT. A stopcock is attached to provide for evacuation and filling. The entire system is blackened outside to keep out light, and then the air to be measured is allowed to enter. Lucas obtained background counts as low as 5 counts per hour (cph), and sensitivities of about 320 cph per pCi. Lucas cells are both inexpensive and reliable, and so are widely used.

Nuclear track detectors are passive monitors that rely on the fact that the high density of ionization produced by alpha particles cause damage when travelling through certain plastics. These damage paths are easily etched away by treating the plastic with a hot alkali solution, forming "tracks," and then the tracks are counted by optical means. The "Track Etch" detector, sold by Terradex Corporation, gives an uncertainty of about 25% when exposed to 1 pCi/l for 30 days (9). Track detectors can be used for exposure periods of up to a year if desired. Such a long exposure period averages out the seasonal variations in radon concentrations, and so provides an better indication of long-term exposure than most other methods, which use shorter time periods.

Because the radon progeny are formed as positive ions, active electrostatic collection through a diffusion barrier can be used to measure radon concentrations. The electrostatic potential is provided by either an external power supply or an electret. The actual detector can be either a track etch detector, a scintillator, or a semiconductor detector. These devices suffer from humidity problems because the number of charged progeny is affected by the amount of water in the air.

Rutherford (circa 1900) long ago showed that radon (all three isotopes) can be adsorbed by charcoal. He suggested that airborne concentrations of radon could be measured using passive adsorption. Charcoal adsorbs radon out of the air at a rapid rate, and eventually the concentration of radon in the charcoal is proportional to an integrated average of that in the air. George demonstrated a simple detector made from a World War II gas mask canister. Other versions have also been developed, including one by Cohen (10), later improved by George (11), which utilizes a metal ointment can containing several grams of charcoal.

In general, charcoal in most detectors adsorbs radon according to Eq (5). (12) The effective volume, V, of the charcoal is strongly dependent upon the temperature. Also, as

$$\frac{dQ}{dt} = fC_0 - (L + \frac{f}{V})Q \tag{5}$$

where

Q = *Rn concentration of charcoal*
C_0 = *Rn concentration of air*
f = *diffusion rate of air into sampler*
V = *effective air volume of charcoal*
L = *radiological decay constant of charcoal*

the radon concentration in the charcoal increases, the rate of adsorption decreases. At some point, equilibrium is achieved. Indeed, if the radon concentration in the air then decreases, the charcoal will release adsorbed radon back into the air. Thus, a weighted time-average of the air's radon concentration is recorded in the amount of radon in the charccal.

One of the major difficulties of this type of detector is that radon is not the only substance taken up by the charcoal. Water is also rapidly adsorbed, so when the humidity in the air is exceedingly low or high, results may vary. Pojer et al (1990) found that after long periods of exposure (about 8 days), water would actually displace radon in the charcoal, leading to low readings. In addition, they found that after a four-day exposure, the uptake of radon was temperature dependent. They developed a model to describe this effect at low humidities, but unfortunately it failed at high humidity. A regression model was used for high temperature conditions; it showed that at 35°C, an increase in relative humidity from 15% to 90% lowered the rate of radon uptake by a factor of three. At room temperature the results were much better; increasing humidity from 20% to 50% only decreased radon uptake by less than 20% (13).

Radon Measurements at AFIT

AFIT students have used a similar charcoal adsorption canister, built by Gill in 1985 (14). The design is the same as the ointment can developed by Cohen (15). The canister has a small window on the top face which allows air to enter. The window is covered with a diffusion barrier made of a double layer of silk screen. The term "diffusion barrier" is a misnomer, because the purpose of the silk screens is not to prevent diffusion, rather it is to ensure that any air crossing the barrier must do so through diffusion. If the air were allowed to pass directly through the window into the canister, the ambient wind conditions would influence the amount of radon adsorbed into the charcoal.A piece of tape lined with aluminum foil serves to seal the canister. These sampling canisters are inexpensive, and may be reused after being baked out in an oven.

The amount of radon absorbed by the charcoal in the canisters is measured by setting the canister on top of a thallium-activated, sodium-iodide scintillator. The output of the detector is sent to a multi-channel analyzer which produces a pulse-height spectrum of the gamma rays emitted from the decays of ^{214}Pb and ^{214}Bi. Gross counts in the ranges of 220-390 keV (Region 1) and 550-680 keV (Region 2) are measured during a half-hour counting time. These counts are corrected for background and a time-integrated average of the radon concentration is calculated.

There are two main problems with this approach. First, the canister, about the same diameter as the detector, is placed on top of the scintillator while being read. The gamma rays are emitted in all directions, and so less than half travel into the detector. In addition, the intrinsic efficiency for counting gamma rays of those energies with a NaI detector is between 30 and 60%. Second, the background count rate is quite high compared with that expected from a canister exposed to environmental radon levels of about 1 pCi/l. A 90 hour background count taken between 13 and 16 July showed 1909 (Region 1) and 612 (Region 2) counts/half-hour. Four canisters exposed in the radon chamber for 24 hours showed average gross count rates of 35,630 (Region 1) and 11,618 (Region 2) counts/half-hour. A typical environmental radon concentration (say 1 pCi/l) would be about one percent of that in the radon chamber, so the net count rate of a canister exposed in the environment would be much less than the background count rate.

The sampling and detection system used in this project uses charcoal adsorption for sampling, and liquid scintillation counting (LSC) for measuring the samplers. The samplers are polyethylene vials, manufactured by Packard. They are about 6 cm tall and 2 cm in diameter, and each has another plastic cylinder inside. The inner cylinder has polyethylene diffusion screens on both the bottom and the top. Between the screens is a mixture of about 1.3 grams of charcoal and about 1 gram of desiccant. The vial has a plastic screw-on cap with a rubber seal. The cap is removed for exposure, allowing air (and radon) to diffuse through the screen into the charcoal and desiccant. The desiccant adsorbs water faster than the charcoal does, providing some immunity to humidity without lowering the diffusion rate.

The amount of radon adsorbed by the charcoal in the Packard vials is measured by counting the emission of alpha and beta rays through liquid scintillation (LS) counting, which has some advantages over gamma ray analysis (16). In the chain of decay events, five emissions of alpha or beta rays occur, while only two decays result in the emission of gamma rays. The emissions originate inside of the scintillation cocktail, except at the inside surface of the vials, so that very few counts are lost due to geometrical factors. It is relatively easy to screen out all external alpha and most external beta particles, leaving a much smaller background count rate. In this experiment, background rates averaged about 15 counts per minute. Finally, the efficiency of counting beta particles in the cocktail is virtually 100%, and only slightly less for alpha particles.

Liquid Scintillation Counting

The amount of radon absorbed by the charcoal in the exposed vials is determined by liquid scintillation (LS) counting. The radon is eluted out of the charcoal by adding a liquid scintillation cocktail, consisting of a solvent and a solute, to the vial. Radon is very soluble in the solvent, xylene, (12.7 cm^3/g at 18°C and 1 atm), so the charcoal releases most of the radon as the gas is dissolved into the xylene. As the radon dissolved in the xylene decays according to the scheme previously described, the various alpha and beta particles emitted deposit their energy in the solvent of the LS cocktail. This energy is then transferred from the solvent to the solute through collisional interactions. A solute, which is fluorescent, relaxes from an excited state to the ground state by emitting a photon. This type of chemical is known as a fluor; the best fluor for LS counting must release its energy quickly, and the wavelength must be detected easily. A photo-multiplier tube (PMT) is used to detect the light emitted; the photo-cathode of the PMT determines the wavelength of the light that is acceptable.

The Liquid Scintillation Counter used for this experiment is a Packard Tri-Carb 2200CA. Packard (a Canberra company) built this model using the concept of coincidence counting of LS samples. Two PMT's are used which are on opposite sides of the LS vial. Any nuclear decay event produces approximately 10 photons for each keV of energy released. All of the energy is released within a time period of about 5 nanoseconds. Therefore, any alpha or beta particle travelling through the LS cocktail will stimulate both PMT's. The output of both PMT's is fed into a coincidence circuit. This circuit produces an output only if both PMT's produce signals within about 20 nanoseconds of each other. PMT's are known to produce spurious signals, and since it is unlikely that both PMT's would spontaneously produce noise pulses within 20 nanoseconds, the coincidence circuit reduces noise. In addition, the coincidence circuit will ignore a single photon entering the vial from an external source, and so reduces the background count as well.

The Packard Tri-Carb 2200CA also includes a summation circuit. By adding the outputs of both PMT's, a signal is obtained which is proportional to the total intensity of the scintillation. Since the total intensity is proportional to the energy of the incident particle, an energy spectrum is easily obtained (17). For radon detection, only that part of the spectrum between about 25 keV and 900 keV is used. Below 25 kev, the background radiation dominates, and above 900 keV none of the decays from ^{222}Rn incite scintillation. The alpha particles in the decay scheme have more energy than that, but because of their high specific-energy loss the efficiency for producing scintillation is diminished. This occurs because some of the molecules of solvent and solute are excited into states which do not result in scintillation. Thus the alpha particles, with energies of 5-8 MeV, generate the same scintillation as betas of less than 1 MeV. As another consequence, the resolution for the alpha particles is about 8% (18).

The Packard Tri-Carb 2200CA Liquid Scintillation Analyzer is controlled by an IBM PS/2 Model 30. The computer allows for easy control of the entire system. It also allows for software manipulation of collected data.

The LS vials, after being exposed, are placed into a Varisette cassette. The cassette holds up to 12 vials and is identified by a Protocol Flag. There are 15 different Protocol Flags, and each represents a user-defined method of analyzing the samples. There is also a System Normalization and Calibration Varisette which uses calibrated sources, a background vial, a ^{14}C vial, and a tritium vial, to calibrate the system periodically.

Three of the user-defined protocols are set up to evaluate the radon vials. These three protocols automatically measure all counts between 25 and 900 keV for one background vial and up to eleven samples. The operator may also select counting time, number of counts for each vial, and number of cycles for each Varisette. Each time a new set of samples is analyzed, the operator must enter the date and time of exposure (i. e., the date and time the vials were sealed). The LSC counts the background vial first, and then each subsequent vial is counted and evaluated. The total number of counts is used to determine the accuracy of the count rate. The computer calculates the square root of gross counts plus background, divided by total counts minus background. This number is doubled and reported as 2 σ in percent. The count rate reported is the gross counts minus background divided by the counting time, and then corrected for decay back to time of exposure. No correction for decay during counting is needed, since the half-life of radon (3.82 days) is much greater than the ten minute counting time.

Protocol for Handling Radon Vials

Sharp developed the protocol for processing the exposed radon vials for his master's thesis (19). A system for the entire process from procurement of vials to disposal was not complete. The system has now been designed and tested.

The vials being used previously were purchased from Packard Instruments, Inc., the same company which sold the Liquid Scintillation Counter to AFIT. These vials performed adequately and will continue to be used.

An attempt was made to procure vials from a second source, EKS RadTech of Trainer, PA. A salesman there agreed to send us six vials free of charge for a trial run (20). The EKS vials are only slightly different in construction from the Packard vials. Packard vials have the desiccant and charcoal mixed together in a plastic cylinder, while the EKS vials have separate bags for each. The top of the EKS vial also has a different diffusion barrier. EKS claims that their vial is immune to humidity effects, and they use a proprietary formula to compensate for the weight of moisture gain in the vial. Both EKS and Packard vials were exposed in the radon chamber, and their performance indicated that either vial will perform well. The EKS vials, however, are more expensive than the Packard vials, so a decision was made to continue using the Packard vials.

III. Development of Integrated Database

The main thrust of this project was to develop a system to measure, record, and analyze radon concentrations in a large number of buildings. An integrated database system was designed for these purposes, and appropriate software was written to implement the necessary operations. This chapter discusses the design and development of the system. The first section details the selection of the commercial program dBase III Plus as the base of the system, the second section discusses the design of the databases and the sub-programs to use them, the third describes the use of the integrated database system, and the fourth section relates some of the shortcomings of the system and how it might be improved. Appendix C is a User's Guide containing detailed instructions on how to perform specific operations.

Selection of dBase III

A database is a software package that allows related sets of data to be stored and accessed in specific ways. Each data set contains the same types of information, for example, an address book contains addresses, phone numbers, etc., for a number of different people. Each separate bit of information, for example the phone number, is called a field. Each group of fields comprises a record, and every record contains the same fields. The data stored in the database may be referenced according to some search condition, for example, in an address book, a sub-list of people living in California may be extracted by the search condition "STATE = CALIFORNIA."

The commercial database package dBase III Plus was selected as the base program for the integrated database for two reasons. First, there was already an on-site license for its use, and so development of the integrated system could begin immediately, without waiting for software to be approved and delivered. Second, dBase uses its own programming language to make the database adaptable. After determining exactly what operations are needed, each function can be programmed into a separate sub-program, and the sub-programs can be called as required by a main program.

At the time this project started, a newer version of dBase, dBase IV, had just been released. After inquiry at several software stores in the area, it was learned that dBase IV had several "bugs" in it and that no more copies were being sold. It was, therefore, deemed unwise to attempt to use the newer version until it was perfected. However, once the bugs are resolved, it may be beneficial to upgrade the integrated database system to the newer version of dBase.

Design of Databases and Sub-Programs

The operations necessary to use the integrated database included input and output operations, calculation of radon concentrations and uncertainties, editing of data, and analysis of data. The required input and output operations were the input of data from both the LSC and from the survey forms, output of data from specific buildings to the respective monitors, and output of data from all buildings to the researcher. A sub-program was designed to calculate the radon concentrations and uncertainties from the count rates and uncertainties of each vial, either as they are entered, or from data already in the database. The data, once stored in the database, may be edited either from a sub-program or using the normal dBase EDIT function. Originally, a sub-program was to be written to analyze the data according to any condition entered by the operator. However, the basic dBase ASSIST menu (called the "Assistant") enables the operator to view or output data using one or more search conditions, so it was unnecessary to write a sub-program to duplicate that function.

The design of an integrated database requires one to understand not only what kind of data is to be recorded, but also how it is to be accessed. The data naturally divided itself into two overlapping groups; the data collected by the survey forms, in which each record contained information on one building, and the data output by the LSC, in which each record included the results from measurements on one vial. A capability to access all the radon concentrations measured in a single building simultaneously had to be designed into the system. The EPA recommends at least one radon concentration measurement for every 2,000 square feet of floor space in a building, so the number of vials would not be the same for every building. Because the number of vials varies for each building, it would be difficult to store the survey form responses and the results from all the vials in the same record, and have all records contain the same fields. Thus, it was decided to use two different but linked databases: the first, to be called "BASBLDGS.DBF," would hold all the responses to the survey forms, while the second, "BASE-RAD.DBF," would contain the results from the separate vials. The building numbers would be recorded in both so that the records could be linked. In this way, all the radon concentrations from a certain building could be referenced together by keying on the building number.

The dBase program provides format screens which can be customized for both entering and displaying data. In these screens, the actual name for each field may be replaced by a longer description, so that the database itself need not be cluttered up by long names (indeed, dBase syntax only allows a field name to be ten characters long). A format screen is set up by selecting the various fields which the operator needs, and then they appear with their field names in a column on the left of the computer screen. The fields may then be moved around on the screen, and the operator can add appropriate comments, either replacing or augmenting the field names. This seemed an ideal way to keep the databases simple and yet provide adequate information on the screen so that the operator would only need the survey form when getting data from the form.

Once it was decided that two databases should be used and what data each would contain, the various fields in each database had to be named. The first few fields in "BASBLDGS" contain information including the building number, the monitor's name, office symbol, and phone number, so short field names could be used to describe the contents. Short names, however, would never suffice for a large number of the fields for the responses to the survey forms. It seemed simplest to name those fields after the question numbers in the survey form, so the 26 fields in "BASBLDGS.DBF" corresponding to the questions in the survey form are named "Q1," "Q2," etc., up to "Q26." The fields were named this way not only because many of these fields defied explanation with a short enough name for dBase syntax, but also because it was expected that the field names would never be displayed; instead dBase format screens would display longer, more descriptive names.

However, a problem with using the format screens for the databases arose. There is a "Status Line" at the bottom of every dBase screen that displays pertinent information such as which database is active, what record is being displayed, etc. The "Status Line" stays on the screen while a format screen is displayed, and so limits the available size of the format screen to about fifteen lines, making it difficult to display or enter all of the fields in "BASBLDGS.DBF". Many attempts were made to avoid this situation, such as injecting blank lines, setting the fields in columns, and setting the fields on separate pages. None were effective. The single format screen was replaced by a series of smaller ones, but this made entering data cumbersome and confusing. Finally, a decision was made to write a program which would handle the input of data from the survey forms, and to allow the data to be displayed in the default dBase screen. Because these fields do not have descriptive names, someone viewing the information in the dBase system needs a copy of the survey form to understand the meaning of the entries. The other fields in both databases do have descriptive names, such as "RAD_CONC," "BLDG_NUMB," "OFF_SYMBOL," etc.

The database which stored the vial measurements needed to contain information about where each vial was located during exposure. Radon concentrations vary in different locations in a building, especially on different floors, and generally the concentrations are higher near sources of the gas such as sumps or in crawl spaces. Concentrations may also vary from side to side of the building, depending on the outside wind direction and speed. It was deemed important to record the location of the vial in a way which would allow using that information for a search condition.

In addition to storing character strings in fields, dBase can attach a memo file to a record, and this option was considered for the location description. However, the memo files are long and require a lot of memory space. In addition, using a memo file for a search condition is difficult at best. Thus, it was decided to use a character field, called "LOCATION," which at present is 20 characters long. The first few characters of this field describe which floor the vial was exposed on, and the rest can be used for a short description of where on that floor it was exposed. Also, any other information about possible sources or sinks of radon should be included, such as "near sump" or "open earth," etc. If this information is recorded using the exact same characters to describe certain details every time, a search condition can be used to access vials exposed under similar conditions.

Use of Integrated Database

The operator enters data from the survey forms into the database "BASBLDGS.DBF" through the sub-program "ADDBLDG.PRG." Each question appears by itself on the screen exactly as it appears on the survey form. Every response is repeated to the operator to ensure correct entry, and then stored into the proper place in the database. The responses to certain questions determine if other questions will be asked, for example, if a building has no basement, there is no need to ask how the basement is finished, so that question is skipped.

A similar program, "ADDVIAL.PRG," was written for the input of the information for each vial, even though a format screen would have worked for this purpose. It was deemed important to maintain continuity between the two databases, so the various operations for the two were designed to be as similar as possible. Normally, several vials will be exposed at the same time in a building, and then processed together, so an option was designed into "ADDVIAL.PRG" to loop through the vial-specific questions after the building information has been entered.

Once all of the data from a vial is entered into the fields in "BASERAD.DBF," the sub-program "CALC_CONC.PRG" automatically calculates the radon concentration and uncertainty from those output by the LSC. The LSC outputs the uncertainty from counting statistics in terms of 2 σ in percent, while the uncertainties in the calibration factors reported by Sharp were given in terms of 1 σ. It was decided to maintain Sharp's convention of 1 σ, and the uncertainty in cpm in the database is recorded that way. Thus, as the operator inputs the uncertainty from the LSC, it is divided by two before being stored. This creates a problem, though, if the dBase edit screen is used to enter the uncertainty in count rate directly, because the operator will not convert the uncertainty from 2 σ to 1 σ. The programs used to edit building and vial information use the dBase edit screens, so the operator is asked at the start of "EDTVIAL.PRG" if the uncertainty is to be entered. If so, that quantity is entered and divided by two before being stored in the database, and then the EDIT screen appears.

The data gathered from a large survey of indoor radon levels is often displayed on a log-normal plot, and a program separate from the main menu was written to translate the vial data into log-normal form for plotting. A log-normal plot displays the logarithm of the radon concentration versus the percentage of all readings which were below that concentration. If all of the readings taken from a survey are normally distributed about a median value, the log-normal plot will show a linear dependence. For this purpose, a separate database, "LOGNORM.DBF," and sub-program, "LGNORM.PRG," were created. A plot was generated for the data obtained in the base survey, but there were an insufficient number of readings to determine if they describe a linear distribution.

Shortcomings of the System

Originally, the database system was intended to analyze the recorded radon concentrations for specific building conditions, but it was later decided to use dBase itself for this function. The ASSIST menu in dBase allows the operator to select one or more search conditions quite easily. After attempting several different programming techniques to perform the same operation, it became apparent that any such technique would not have the desired versatility, indeed would be more limited than dBase. However, this creates a shortcoming in the system. Since the field names for the questions on the survey form are not descriptive of the responses, the operator must have a copy of the survey form when viewing the data. This situation could be alleviated by the creation of several format screens, each selecting certain fields for display.

The integrated system also has an option to generate a report for the researcher based on some search condition, but the option has not been implemented for the following reasons. First, the report would need to change to reflect whatever search condition was selected. Second, since the dBase ASSIST menu will be used to select the search conditions, it can also be used to display or output the results. Finally, it is only worth the effort required to write a program if that program is to be used over and over again, and it is unlikely that any search condition would be repeated more than a few times. In any case, search conditions may be stored in dBase in a "Query" file for later use.

At present, the location field contains all the information concerning where the vial was exposed and any ambient conditions, but this field should be divided up. It is much easier to perform a search operation when the key field contains only one piece of data. It is difficult, then, to search the location field for certain type of exposure, and if all similar entries are not spelled exactly the same way in every case, it is almost impossible. This presents a problem, and so the location field should be divided up into more fields. One of the new fields should certainly be the floor at which the vial was exposed. Four options would probably suffice here; basement, crawl space, ground floor, and other (upper stories). Another new field might be possible sources of radon, such as near a sump pump. Breaking up the location field this way would greatly facilitate accessing the database using a search condition.

IV. Results

Determination of Calibration Factor

In his thesis, Sharp had evaluated the results from many exposed vials, and determined a calibration factor (FAC) with which the radon concentration could be determined from the corrected count rate. The FAC he had found, however, was for those vials processed by his Protocol 1, not the Protocol 3 that he decided would be best to use. Both protocols begin with the exposed vials being filled with Insta-Fluor, and then being set upside-down for 24 hours to elute the radon out of the charcoal into the LS cocktail. The Protocol 1 vials are then counted, while the Protocol 3 vials are set upright for another 24 hours. One of the first experimental goals of this project was to determine if a correction to the FAC for Protocol 1 would be required to use Protocol 3.

With that goal in mind, ten vials were exposed inside of the radon chamber simultaneously. Two more vials, unexposed, were selected to serve as background. Five exposed vials and one unexposed vial were processed according to Protocol 1, and the others were processed according to Protocol 3. The Protocol 1 vials were counted repeatedly while the Protocol 3 vials were setting upright the additional day. When the Protocol 3 vials were ready, they were also counted repeatedly for the same period of time. The measurements for each vial were averaged, and the results shown in Tables 5 and 6. Averaging the results from each of the two groups of vials gave an average count rate for the five vials processed by Protocol 1 of 3840 ± 62 counts per minute (cpm), and those processed by Protocol 3 of 3882 ± 53 cpm, where the uncertainties are the standard error of the mean for each set of five average values.

Table 5. Results for Vials Processed by Protocol 1

Vial #	Type	Count Rate (min^{-1})	Uncertainty 1 σ (%)*
2	background	14.1	1.90
11	chamber	3873.5	0.12
13	chamber	3907.4	0.12
15	chamber	3971.8	0.12
17	chamber	3838.8	0.12
19	chamber	3610.0	0.12

* Note: Uncertainties in Tables 5 and 6 are the standard deviations derived from counting statistics alone.

Table 6. Results for Vials Processed by Protocol 3

Vial #	Type	Count Rate (min^{-1})	Uncertainty 1 σ (%)
20	background	15.0	1.80
10	chamber	3951.8	0.11
12	chamber	4044.7	0.11
14	chamber	3766.9	0.11
16	chamber	3871.4	0.11
18	chamber	3775.9	0.12

Since the difference between the averages of the count rates for the two sets of five vials is only 42 cpm, while the standard errors for the two sets are 62 and 53 cpm, the variability between vials is greater than the difference between protocols. Thus no correction for protocols has been used. All radon concentrations determined from count rates in this report have been calculated using Sharp's calibration factor for vials processed by Protocol 1.

Development of Survey Forms

The survey forms used in this study to obtain information about the buildings being tested were developed based upon the EPA's questionnaire (21) for their national study of residential radon levels. The EPA's survey questionnaire is about 30 pages long, and requests information that was deemed unnecessary for this study. The 77 questions in the EPA survey were reduced to 26. In addition to this reduction, some of the questions were rephrased for clarity (the EPA uses an "interviewer" to help the homeowner answer the questions). The form of some of the answers have also been changed, in order to better fit the database developed to store them.

In addition, the building monitors of the seven buildings tested provided valuable input to the design of the survey forms. Some of the questions and responses that seemed clear to the researcher were not clear to the monitors, and have been rephrased. The survey forms for the last few buildings tested were filled out completely without assistance, so hopefully, the survey forms are now self-explanatory, and a building monitor can respond to all questions correctly.

Survey of Radon Levels in Buildings on WPAFB

A preliminary survey of radon concentrations in selected buildings on base was conducted. The purpose was to verify the operation and practicality of using the system to test large numbers of buildings. Table 7 is presented here as an example, the results for the other buildings are presented in Appendix A.

Table 7. Results for Vials from Building 8

BLDG	Location	S/N	[Rn] (pCi/l)	1 σ (%)*
8	Bsmt on shelf	026695	4.25	7.73
8	1st, bureau	026696	4.21	7.74
8	Bsmt, near sump	026700	11.33	7.21
8	2nd flr supply room	026701	4.37	7.72
8	2nd flr office	026703	4.18	7.76

* Note: Uncertainties in Table 7 are determined by adding the uncertainties from counting statistics and variability of the vials in quadrature, and then adding the systematic error from determination of Sharp's calibration factors.

Building 8 is the Arnold House, probably the oldest building on base (approximately 140 years), and is named for General "Hap" Arnold, who lived there for several years. The data in Table 7 shows that the radon concentrations in the Arnold House are at (given the uncertainty) or above the EPA's action level for every sample. The highest reading found anywhere in the preliminary survey is near the sump in the basement of this old house.

The other tested buildings on base (see Appendix A) were found to be under the EPA's action level of 4.0 pCi/l, with the exception of Building 201. That building has no basement; it is built over a crawl space. The floor which separates the interior from the crawl space is only wooden planks, and does not provide an airtight seal. Thus radon emanating out of the ground may migrate into the building directly through the floor.

Neither Building 201 nor the Arnold House had so high a concentration of radon as to be considered for immediate treatment by the EPA. The recommended course of action for these two buildings is for a long-term measurement of the annual average of the radon concentration.

The system developed for the measurement of radon levels performed quite well. The biggest problem encountered had little to do with the measurement and data collection system itself, but rather logistics. For example, since the vials need to be exposed for 24 hours and most buildings on an air force base close down on weekends, the vials had to be set out by Wednesday of each week. Two appointments with the building monitor had to be set up a few days in advance at his convenience, for setting out and picking up the vials.

Another common difficulty was the laymen's fear of radiation. People in an area which was to be tested often expressed anxiety about the reason for testing. They assume that their particular area is selected for testing because some evidence had arisen that dangerous levels of radon were present. It was important to inform the people in the area that there was no known danger, and that radon testing is a first step in assuring a safe workplace.

The building monitors themselves often expressed concern as well. A letter from the Environmental Management Office served to inform them that this project was in collaboration with the on-going RAMP program. The monitors were also concerned about the use of toxic chemicals or obtrusive detectors; simply showing them a detector alleviated those fears.

The monitors helped out in the design of the survey forms. After the first few buildings had been tested, the forms were simplified to the point where they could be filled out easily, without any help from a researcher.

V. Conclusions and Recommendations

Conclusions

The integrated database performs admirably. The operator is only required to enter each question from the survey form and the pertinent data about each vial. The database software then performs the necessary calculations to fill in the rest of each record. The database can be used to view and edit the data through normal dBase operation, or can be used through the menu system. In addition, the menu system provides for automatic generation of reports for each building monitor, notifying him of the building's results. The report also tells him if any of the vials recorded a radon concentration above the EPA's action.

However, the operator must have a copy of the survey form when viewing the data in the database. This means that the database cannot be viewed or the data explored without the survey form. The incorporation of a series of format screens, each displaying part of the data with the necessary descriptions, would alleviate this problem.

On the other hand, the use of dBase III Plus as the basic database program still allows for quick analysis of the data accumulated. Searching for correlation of items such as high radon concentrations in basements or with age of the building can be easily accomplished.

The survey of radon concentrations on Wright-Patterson Air Force Base showed no dangerously high concentrations of radon gas in any of the buildings tested. A few locations were found to be at or slightly above the EPA's maximum recommended concentration, and the building monitors and the Environmental Management Office were notified that further testing should be conducted.

Recommendations

To improve the accuracy of the calculated radon concentrations and improve the database, the following actions are proposed:

1. Build into the radon chamber a system for regulating the radon concentration, the humidity, and the temperature. As of now, the calibration factors used were determined by Sharp in the radon chamber at EML. It would be better if the system could be calibrated on-site. Varying the humidity in the chamber while exposing vials would possibly lead to the development of an empirical relation to compensate the radon adsorbed for the ambient humidity or weight gain of each vial.

2. Obtain certification for public radon testing from the EPA. As stated previously, they are currently revamping their process, so it is impossible to predict when this could happen.

3. Complete the program called out in the main menu of

the database which has yet to be written. The program to generate a report on an analysis of the acquired data is awaiting a decision on what type of analysis will be taken. An analysis program was not written because there are so many different ways to analyze the data, it could not be decided which would be implemented. Anyway, it is a simple matter to compare radon levels for one or more particular attributes of buildings, for instance near the sumps.

4. Develop a number of format screens to view related data, for instance, all buildings with basements. Several format screens would have to be accessed consecutively to view all fields, but generally the operator will only wish to view a few at a time.

5. Break up the location field of "BASERAD.DBF" into smaller fields to facilitate search operations.

6. An investigation into the changes made in dBase for the release of dBase IV should reveal if upgrading to that version would improve the current system. If so, changing the system to the newer version should be considered.

Appendix A. Results of Base Survey of Radon Levels

Table 8. Results for Vials from Building 31

BLDG	Location	S/N	[Rn] (pCi/l)	1 σ (%)*
31	1st, air compr	026799	0.69	13.62
31	3rd flr, Rm. 306	026810	0.58	15.00
31	Gnd flr, instr. rm,	026816	0.98	11.65
31	below gnd, Baldwin	026817	2.03	9.13
31	Gnd flr, behind tire	026822	0.77	12.98
31	Gnd flr, pump room,	026824	0.81	12.70
31	Gnd, av hv room, N	026825	0.75	13.23
31	Gnd, copy room, NW	026826	1.02	11.51
31	Gnd, storage, E	026827	0.75	13.26
31	Gnd, nr sump, force	026828	0.65	14.27
31	1st flr conf. room	026839	0.67	14.05

* Note: Uncertainties in Tables 8-13 are determined by adding the uncertainties from counting statistics and variability of the vials in quadrature, and then adding the systematic error from determination of of Sharp's calibration factors.

Table 9. Results for Vials from Building 71B

BLDG	Location	S/N	[Rn] (pCi/l)	1-σ (%)
71B	GRD FLR, Oil Storage	026814	0.66	15.15
71B	Rm 143 office E	026801	1.22	11.27
71B	bsmt, rig 1 control	026823	0.71	13.21
71B	2nd comp contr room	026834	1.70	9.51
71B	bsmt, nr sump eq rm	026835	0.74	13.04
71B	bsmt aux oil room	026841	0.63	14.10

Table 10. Results for Vials from Building 20

BLDG	Location	S/N	[Rn] (pCi/l)	1 σ (%)
20	Bsmt, rm 014	026815	0.70	13.61
20	gnd, chem strg, wate	026818	1.17	10.85
20	2nd flr, Rm 201	026820	0.54	15.75
20	Bsmt, rm 404 mp proc	026829	0.50	16.46
20	Bsmt, Rm. 038	026830	0.56	15.52
20	1st flr, Rm 104	026836	0.53	16.07
20	Bsmt, 003, sump	026838	0.70	13.84
20	2nd, large open area	026844	0.50	16.71
20	1st, 122, Bush offc	026845	0.57	15.42
20	Bsmt, 019, drkrm	026846	0.64	14.53
20	Bsmt, Rm 055	026851	0.63	14.75

Table 11. Results for Vials from Building 450

BLDG	Location	S/N	[Rn] (pCi/l)	1 σ (%)
450	Bsmt B nr sump	A	0.83	11.41
450	C Bsmt nr sump, dirt	C	0.16	30.81
450	Gnd ofc D 02	D	0.22	24.77
450	E gnd eqp rm nr pit	026853	0.15	33.58
450	Gnd A, ofc A04	026854	0.36	17.70
450	Gnd flr lab, D08	026862	0.31	19.47
450	Bsmt B high bay	026873	0.09	53.47

Table 12. Results for Vials from Building 620

BLDG	Location	S/N	[Rn] (pCi/l)	1 σ (%)
620	Bsmt, DeBra contr, g	B	0.46	14.81
620	Gnd Mod C, C-D2	E	0.26	20.99
620	Gnd, NE1, HH2	026855	0.28	20.14
620	Bsmt, elev shft #3,	026856	0.26	21.13
620	Bsmt, red, near sump	026857	0.28	20.52
620	Bsmt, orng, SW corne	026865	0.31	19.00
620	Bsmt, ylw, near sump	026869	0.28	20.14
620	Gnd Mod B, B2	026870	0.63	12.90
620	Gnd W eqp rm, Twr	026871	0.32	18.95
620	Gnd NE2 R27, drain	026876	0.60	9.41
620	Gnd Mod A Ofc Hary W	026954	0.60	- 1.07

Table 13. Results for Vials from Building 201

BLDG	Location	S/N	[Rn] (pCi/l)	1 σ (%)
201	1st flr large office	026694	4.02	9.26
201	1st flr storage room	026697	3.50	9.57
201	1st Ladies room	026699	4.16	9.19
201	121, radium dials	026702	5.12	8.80
201	119, Utility room	026698	4.60	8.99

Appendix B. Survey Form

INSTRUCTIONS FOR USING "RADON VIAL"

Generally you will receive several vials to measure the radon level at **two separate regions** in your building. The radon level both in working areas and at possible sources of radon gas should be measured. Since radon emanates from soil, rocks, and possibly water, place one vial in the basement in an area containing either a sump or drain. Place other vials in areas occupied most often; for example, offices, labs, etc. **Locate the vials far enough above the floor and away from windows to avoid drafts**; i.e., the vial should be sampling air that is representative of that which you normally breathe.

PROCEDURE

1. Place the vial upright in the room to be monitored.

2. To start the test, remove the cap from the vial. Keep the cap by the vial to assure that the same cap gets back on that vial.

3. Record time and date of opening. Use the space provided below.

4. Leave the vial undisturbed for two days; i.e., 48 hours.

5. To end the test, replace the cap on the vial. Make sure the cap is securely fastened.

6. Record the time and date that you sealed the vial.

7. **Return the vial as soon as possible**, preferably on the same day that the test was ended. It is essential that we receive the vials no later than three days from the end of the test.

PROVIDE THE INFORMATION REQUESTED BELOW

NAME________________________ BUILDING______________________
AREA________________________ OFFICE SYMBOL ___________
PHONE_____________________ DATE_____________

VIAL S/N LOCATION TIME OPENED TIME SEALED

The following questionnaire is designed to provide information pertinent to radon hazard sources, risks, and possible mitigation. Please answer all questions as completely and truthfully as possible. All responses will be kept in the strictest confidence, and used only for our studies.

1. Which of the following best describes this building?
   a. Multi-unit building
   b. Single-unit building
   c. Mobile home
   d. Other (describe) ________________

2. How many levels or stories does this building have?
   a. Single story
   b. Split level
   c. Two-story
   d. 3 or more stories

3. Approximately how many square feet of floor space is there on the bottom story or basement? _______________

4. About how old is this building? _______________ yrs.

5. Does this building have a full or partial basement, a cellar, or a level which has one or more walls partially or completely below ground level? Such a level will be considered a basement. Note: If the answer to this question is no, skip to question 11.
   a. Yes
   b. No

6. What are the outside walls of the basement made of?
   a. Concrete block or cinder block
   b. Poured concrete
   c. Stone and mortar
   d. Wood
   e. Brick or brick veneer
   f. Earth, dirt, clay, etc.
   g. Other (describe) _________________

7. Describe the approximate percentage of each type of treatment of the inside of the outer walls of the basement:

a. ___% Untreated
b. ___% Panelling without insulation
c. ___% Panelling with insulation
d. ___% Paint
e. ___% Sealant or airtight paint
f. ___% Other (describe) ____________________

8. Is any part of the basement floor exposed earth?

a. Yes
b. No

9. Are the any unsealed passages between the basement or crawl space and the interior of the building?

a. Yes
b. No

10. Is the primary heating system in the basement or crawl space?

a. Yes
b. No

11. Is there a sump pump in the main drain for the basement or crawl space?

a. Yes
b. No

12. What percentage of the building is over a...

a. Basement.............. _____%
b. Concrete slab......... _____%
c. Crawl space........... _____%
d. Open air.............. _____%
e. Something else........ _____% (describe) ______

13. Describe any other concrete or asphalt surfaces attached to or bordering the foundation:

a. None
b. Driveway
c. Parking structure or carport
d. Patio
e. Loading ramp
f. Other (describe) _________________

14. What type of distribution system is used for primary heat?

a. Forced air
b. Hot water or steam (radiator, baseboard)
c. Natural convection (fireplace, woodstove, etc.)
d. Other (describe) ________________

15. What fuel is used for primary heating?

a. Natural gas
b. Electricity
c. Oil
d. Coal
e. Propane or bottled gas
f. External steam source
g. Wood
h. Other (describe)

16. Is any part of this building excluding the basement built on a concrete slab?

a. Yes
b. No

17. If the primary heat source is some kind of combustion, is outside air brought in to replace the exhaust going up through the chimney?

a. Yes
b. No

18. Is there an air-to-air heat exchanger or heat-recovery ventilator in this building? (Note: Such a system blows stale air out of the building, brings in fresh air from outside, and transfers heat from the stale air to the fresh air.)

a. Yes
b. No

19. Does this building use the base water supply, or is the water drawn from a private well?

a. Base or public water supply
b. Private well

20. Does the building have any of the following gas or propane fueled appliances?
   a. Water heater
   b. Clothes dryer
   c. Stove/Oven
   d. Refrigerator
   e. Air conditioner
   f. Heat pump
   g. Fork Lift
   h. Other (describe) ______________________

21. Does this building have central air conditioning?
   a. Yes
   b. No

22. Does this building have any of these other A/C systems?
   a. Window or wall-mounted units
   b. Swamp or evaporative coolers
   c. None

23. Does the building have an exhaust fan which blows air outside? If not, skip question 24.
   a. Yes
   b. No

24. How often is the exhaust fan used during the cooling season?
   a. Every day
   b. Not daily, but more than once a week
   c. Regularly, but less than once a week
   d. Seldom or never

25. Overall, how tightly sealed is this building?
   a. Tightly
   b. Moderately
   c. Leaky
   d. Don't know

26. Considering both heating and cooling seasons, about how many months of the year is the building sealed up, that is, windows and doors usually closed? __________

Appendix C. User's Guide for dBase Software

The commercial software package dBase III Plus was used to develop an integrated software system. The system is capable of recording the responses to all questions posed by the survey forms and the data from each vial analyzed, and can generate a reply to the building monitor. Each separate program is user-friendly and contains checking for improper entries. They will each be discussed in the order in which they appear in the main menu.

The integrated system utilizes two separate but linked databases. The first, "BASBLDGS.DBF", holds the data about each separate building tested. The data is obtained from the building monitor's answers to the 26 questions in the survey form. The second database, "BASERAD.DBF", contains the results from the analysis of each vial. The operator enters this information after completing testing on each sample. The two data bases are linked by building number; each vial's record contains the number of the building where it was exposed.

In order to run the dBase system, an IBM PC-clone is required, along with a licensed copy of the commercial database program dBase III Plus. At present, the entire package requires installation on a hard drive, but it is possible to run it with only a floppy drive. Each program would have to be modified wherever a file is called, whether that file is a database file or a command file. The insertion of "A:\" in front of each file name in every program would allow the PC to find them on the A: floppy drive. This would not be as difficult as it seems; database file names always occur after "USE", and command files are always preceded by "DO". The command "USE" appears only with a database file, and the only other usage of "DO" in a program is in conjunction with "WHILE" or "CASE".

After installation on the hard drive (or modification as described above), the dBase program is started by entering "dBase". Pressing the "Esc" key begins the "dot-prompt" mode of dBase, and then the integrated database system is started by entering "DO MAINMENU". The Main Menu screen appears, with a list of options. Any desired task is selected by simply pressing the "TASK CODE" key for that function.

Task Code 1 is pressed to add a new building to the database "BASBLDGS.DBF". If the completed survey form for the building is in hand, all answers to the questions can be fed into the database by responding to the questions as they appear on the screen. The program first determines if the building to be added is already in the database; if it is, the user is informed of that and control returns to the main menu. Otherwise, a new record is created for the building, and the answers are stored into the database as they are entered. After all questions have been answered, the mainmenu reappears. The addition of a building to the database is by far the most time-consuming of all of the options, since there are 26 questions in the database.

Task Code 2 adds the results from a new vial into the database "BASERAD.DBF". The vial's serial number is checked to ensure it is not already in the data base, and then all of the data can be entered. Usually, vials are exposed in groups (several in the same building for the same period of time), so an option exists to enter more vials exposed with the first in the same building. The serial number of the vial being entered is displayed in the upper right corner of the screen, so the operator knows which vial he is entering. The weight gain in grams is calculated from the pre-exposure and post-exposure weights. The program CALC_CONC.PRG is used to calculate the radon concentration and uncertainty for each vial from the corrected count rate and 2-σ error reported by the LSC.

The next two options, task codes "3" and "4", are used to edit either building or vial data which has already been entered. Control is transferred to the normal dBase editing screen, where as much of the selected record as the screen can hold will be displayed. The rest of the record can be displayed by pressing "PgDn." Any single entry can be edited by placing the cursor on the desired entry and entering the correct data. The only items that require any other considerations are CPM_SIGM, the uncertainty in count rate, and CONC_SIG, the uncertainty in radon concentration. The latter is calculated from other quantities, and the former is reported by the computer as 2-σ (%), but is recorded in the database as 1-σ (%). Thus, if CPM_SIGM is entered from the edit screen, the number input must be half of the LSC's reported uncertainty. Answering "Y" to the question, "Do you wish to change the count rate or uncertainty?" provides for automatic conversion, calculation, and storage of both numbers.

Task Codes "5" and "6" allow for removal of old building and vial records from the database files. In both cases, the program finds the desired building or vial, and then double-checks before deletion. If a building is deleted, an option appears to allow for deletion of all the vials which were exposed in the building.

Task Code "7", which is set up to generate a report on the accumulated data for research purposes, has not been implemented. No program was written for this option because it is not clear what type of report should be generated. In addition, the basic dBase program allows for analysis and output of selected records, as will be discussed further below.

Task Code "8" generates a reply letter to the building monitor. After the building number is input, the program locates the building information in "BASBLDGS.DBF". The necessary data is collected and put together into a letter, addressed to the monitor. The individual vials' serial numbers, exposure locations, measured radon concentrations, and uncertainties are put into the letter in table form. Next, the highest concentration read is compared to the EPA's action level of 4 pCi/l, and an appropriate response is chosen, based on whether the level was below, at, or above the EPA's action level.

The dBase III Plus program itself allows for searching the data for a multitude of conditions. It is inappropriate to rewrite the user's guide for dBase here, but any desired search condition or conditions can be implemented through dBase's powerful ASSISTANT. The dBase manual should be consulted for instructions.

The sub-program "CALC_CONC.PRG" was written to provide automatic calculation of radon concentrations and uncertainties from the outputs of the LSC. The length of exposure of each vial is used to determine what the calibration factor will be. Sharp determined calibration factors (FAC's) for several different exposure periods, 15.5, 24, 30.5, 48, and 72 hours. These FAC's are used in discrete fashion, that is, the closest period of exposure to those above is selected, and that FAC is used to determine the concentration and uncertainty. An empirical relation was not developed, because the FAC so determined for an exposure time between two of those above periods would not be statistically different from the FAC of either time period. Thus, an attempt should be made to keep exposure times as close as possible to one of the above periods.

Appendix D. Instructions for Use of Radon Vials

The first step in using the Packard vials is to weigh them before exposure. An electronic scale accurate to one hundredth of a gram is sufficient. It is expected that any vial gaining more than a few tenths of a gram during exposure will indicate a lower radon concentration than was actually present. Even in the high humidity in an Ohio summer, this was not a problem for most of the vials used, but the weight gain should be recorded for reference. The vials' pre-exposure weights can be measured weeks ahead of time, if desired.

The next step is to expose the vials. A vial should be placed away from drafts and open water; it should sample the same air that people would normally be breathing. After determining where the vial is to be placed, it should be opened, and the cap left next to it. It is important to replace the same cap onto the vial after exposure; the caps' weights are inconsistent. The vial should be left undisturbed for as close to 48 hours as possible. The 48 hour time period is not critical; an hour more or less probably has less effect on the amount of absorbed radon than natural fluctuations in the radon concentration does. Still, the calibration factors used to calculate radon concentration from the measured count rate are based on a two-day exposure. Therefore, the forms which go with the vials ask for the opening and closing times.

After exposure, the following steps, including reweighing, filling with Insta-Fluor, and analysis, should be carried out as soon as possible. After a delay of only about three days the accuracy of the results begin to diminish. The count rates are corrected for radioactive decay by the LS counter, but a smaller actual count rate ensures greater uncertainty.

First the vials must be weighed again. The database will automatically calculate the weight gain. Again, any weight gain of more than a few tenths of a gram casts doubt on the resulting count rate. The vials should be weighed alone; that is, remove any extra tags or support devices. They should be weighed exactly the same way after exposure as before, so that the only difference is due entirely to moisture gain.

The liquid scintillation cocktail needs to be added next. The mixture used here was a commercial product, Insta-Fluor. Since it is a xylene-based liquid, it must be opened only inside of an approved hood. Xylene fumes have been shown to produce liver cancer in laboratory animals. Xylene also enters through and irritates the skin, so care should be taken in dispensing it into the vials. Most gloves do not seem to help; the penetrating xylene seems to just migrate through them. It is important to wash the hands after filling vials.

Each vial should be filled with 14 milliliters of Insta-Fluor. Scintillation is highly dependent upon the amount of cocktail added, so a Dispensette is used to accurately add the correct amount. The vial's cap should be removed, and then the Insta-Fluor should be added slowly until the level of the liquid is just above the diffusion barrier (at this point 11-13 milliliters have been added). The vial appears to be full, but air is trapped under the diffusion barrier. The air may be released by replacing the cap lightly (not too tight or the Insta-Flour will spurt out on reopening), and turning the vial over slowly. It should be turned so that the side of the vial where the diffusion barrier is farthest from the inside wall points up (the inner cylinder is offset from the center; see Figure 1). This will allow the air bubble to escape above the barrier. Then the vial may be righted and opened again. The rest of the Insta-Fluor may now be added easily. The cap should now be replaced, and care taken to ensure that the O-ring seal is not twisted. Now the cap should be tightened securely so that no Insta-Fluor can escape. The next vial should be filled in the same way, until all vials exposed at the same time are filled. At this time, one more, unexposed vial should be filled to serve for background counting.

All filled vials should be placed upside down in one of the counter's Varisettes (1, 3, and 6 are set up for radon counting), and the time recorded. The background vial must occupy the first position in the Varisette. The vials need to sit upside-down for 24 hours. During this time, the radon which has been adsorbed by the charcoal is eluted out into the

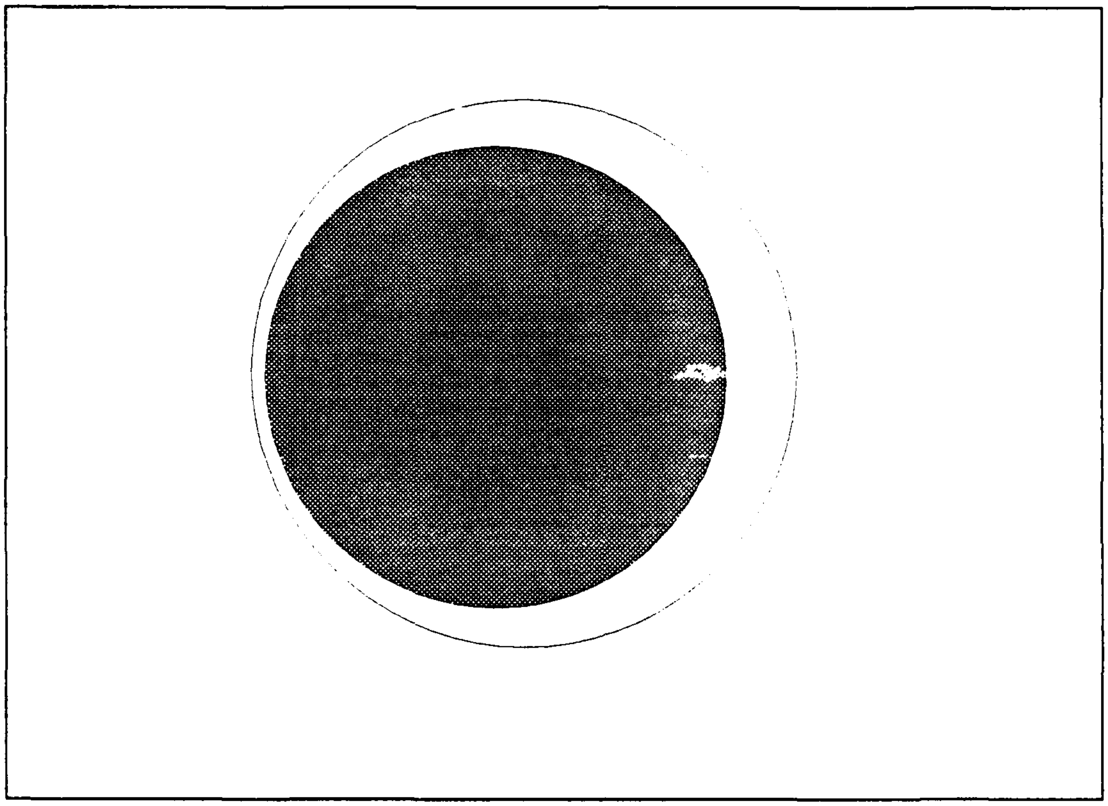

Figure 1. Top View of Radon Vial

Insta-Fluor, and radioactive (secular) equilibrium between the radon and its progeny is obtained.

After 24 hours, the vials need to be set upright in the Varisette, and left for another 24 hours. Sharp found that some fine particles of charcoal could be seen in the liquid after counting if they were not allowed to settle out. Dark particles in the liquid could easily absorb some of the feeble light from scintillation.

After the 24-hour settling time, the entire Varisette is placed into the LS counter, with the background vial in the first position. The Cycle Reset Flag on the Varisette (inside upper left corner) needs to be pushed over to the left so that it sticks out. If the flag is not pushed to the left, the Varisette will not be counted by the LSC. Shaking the vials in the Varisette any more than is absolutely necessary will allow the particles to mix with the liquid again, so the Varisette must be handled gently. The LS counter is kept at 14°C to reduce noise from the PMT's, so the vials must sit inside the LSC for about two hours before counting to come into thermal equilibrium with the counter.

The LS counter itself needs to be set up for counting. Normally the screen will be blank, as the screen saver prevents burn-out, but pressing any key brings the screen back. The "STATUS PAGE" screen will usually appear. Function key "F1" calls up the "*EDIT PROTOCOL*" screen. Enter the number for the Varisette just loaded (1, 3, or 6), and press "ENTER". Protocols 1, 3, and 6 are already set up with the following: one cycle, ten minute counting time, one count/vial, one vial/standard, one vial/sample, 1st vial background, and the radionuclide "manual". Region A should be set for 25-900 keV. The above settings are appropriate for accurate counting of the radon adsorbed in the Packard vials.

The radon decay constant of 91.76 hours needs to be set in the "ADDITIONAL FEATURES" screen. It is accessed by pressing "PgDn" from the "EDIT PROTOCOL" screen. The only change necessary is to reset the exposure date and time. The cursor should be moved until it is at the "Ref Date? A:" position. This date and the "Ref Time? A:" need to be set to the date and time <u>when the group of vials was sealed after exposure</u>. Pressing "PgDn" again brings up the second "ADDITIONAL FEATURES" page. There is an option to enter a remark to be displayed with the count rate in the print-out. Some comment should be entered here which will document where the vials were exposed, such as "Building 620, Area B".

It is possible to retain the counting data from the last run of each protocol in a file on the hard disk of the PS/2. The desired directory must be specified in "Data Application and Path?", and "Save Data" must be enabled. Once finished with editing the protocol, pressing "F1" brings back the "STATUS PAGE".

To start the counting operation after the two hour wait, function key "F2" is pressed. Any Varisettes in the counter will be moved around in a counter-clockwise direction. A Varisette reaching the counting area (rear), if its counting flag is to the left, will be moved sideways until the first vial is in position. That vial will drop down into the counting chamber, and counting begins. The first vial must be a background vial, because each subsequent vial's count rate is reduced by the background count rate, and then the net rate is corrected for decay.

Occasionally, a vial will cause the shutter of the counting system to remain open. When this happens, the computer stops the counting process and the message "SHUTTER CLOSE" appears in red on the computer screen. In order to recover from this situation, the Varisette cartridge must be moved out of the counting area. Pressing "F3" from the "STATUS PAGE" causes the "SAMPLE CONTROL" screen to be displayed. From here, the Varisette may be moved forward, backward, or stopped by pressing appropriate function keys. In addition, the sticking vial may be retried by the "NEXT SAMPLE" option. Sometimes it is possible to save a sticking vial by removing the cap, adjusting the O-ring seal, and reseating the cap. Often, however, the offending vial must be removed and discarded.

Once all the usable vials have been processed, they can be removed from the counter. The print-out should also be taken at this time. The printer must be turned off-line, the form feed button on the printer pushed, and then the page with the count rates on it can be removed. It is important to set the printer back on-line at this time.

The used vials should be disposed of in the following method. All of the used vials should be brought back into the hood. There is an open container there which is labelled "Insta-Fluor and Insta-Gel Waste." The liquid from each vial may be poured into the waste container. Then a small amount of the toluene (about 2 ml) should be put into the empty vial, the cap replaced, and the toluene shaken around inside the vial to rinse it thoroughly. The excess toluene can then be dumped into the waste container. The cap should be left off of the vial inside the hood. This procedure should be repeated for each used vial. After the vials have sat open for about two or three days, they will be dry and can be discarded into the trash. They are not considered radioactive waste since the levels are so low and the radon is from natural sources. The xylene and toluene, however, are hazardous and their fumes must be allowed to dissipate before throwing the vials away. Likewise, the large "Insta-Fluor and Insta-Gel Waste" container is left open to evaporate, and then the residue may be disposed of as chemical waste when necessary.

```
****************  MAINMENU.PRG  **************************
SET TALK OFF
SET ECHO OFF
STORE " " TO CHOICE
DO WHILE .T.
    CLEAR
    ?"                 ************************************"
    ?"                 ***            MAIN MENU           ***"
    ?"                 ************************************"
    ?
    ?
    ?"                   Task Code              Task"
    ?
    ?"                       1            Add New Building"
    ?"                       2            Add Vial Data"
    ?"                       3            Edit Building Data"
    ?"                       4            Edit Vial Data"
    ?"                       5            Delete building"
    ?"                       6            Delete Vial Data"
    ?"                       7            Generate report"
    ?"                       8            Generate reply"
    ?"                       Q            Quit"
    ?
    CLOSE ALL
    WAIT "            Enter desired Task Code: " TO CHOICE
    DO CASE
        CASE CHOICE="1"
            DO ADDBLDG
        CASE CHOICE="2"
            DO ADDVIAL
        CASE CHOICE="3"
            DO EDTBLDG
        CASE CHOICE="4"
            DO EDTVIAL
        CASE CHOICE="5"
            DO DLTBLDG
        CASE CHOICE="6"
            DO DLTVIAL
        CASE CHOICE="7"
            DO GENRPT
        CASE CHOICE="8"
            DO GENRPLY
        CASE UPPER(CHOICE)="Q"
            RETURN
        OTHERWISE
            LOOP
```

```
    ENDCASE
ENDDO


****************** ADDBLDG.PRG *******************
*** PROGRAM TO ADD NEW BUILDING TO BASBLDGS.DBF  ****
SET TALK OFF
SET ECHO OFF
USE BASBLDGS
*
*  Following lines check to see if building is already *
*  in the database, adds it if not, exits if so.       *
KOUNT = 0
ACCEPT "Enter the new building's number: " TO BLDGNUM
COUNT FOR BLDG_NUMB=BLDGNUM TO KOUNT
IF KOUNT>0
    ?
    ?
    ?"           Building is already in database!"
    ?"           Use Task Code 3 to edit it."
    ?
    WAIT"           Press any key to continue...."
    RETURN
ENDIF
*
*  Add the new building's number; *
APPEND BLANK
REPLACE BLDG_NUMB WITH BLDGNUM
*
*  Now a new blank record has been added, with only  *
*  the building number.  The following questions will*
*  appear separately on the screen, and each can be  *
*  answered.  Inputs are automatically entered into  *
*  the database.                                     *
*  Entries are checked before use.                   *
CLEAR
@10,0 SAY "What area is this building in?"
?
?
WAIT "Enter A, B, C, or Kittyhawk (K):  " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="A" .OR. CHAR="B" .OR. CHAR="C" .OR.
              CHAR="K")
     @13,0 SAY "Improper entry.  Try again.          "
     WAIT "Enter A, B, C, or Kittyhawk (K):  " TO CHAR
     CHAR=UPPER(CHAR)
ENDDO
REPLACE AREA WITH CHAR
CLEAR
CLEAR MEMORY
```

```
OPT=.F.
DO WHILE .NOT. OPT
     @10,5 SAY "Select monitor's salutation:"
     @12,10 SAY "a.  Mr."
     @13,10 SAY "b.  Ms."
     @14,10 SAY "c.  Mrs."
     ?
     ?
     WAIT "Enter choice (a, b, c):  " TO CHAR
     CHAR = UPPER(CHAR)
     DO WHILE .NOT.(CHAR="A" .OR. CHAR="B" .OR. CHAR="C")
          @19,0 SAY "Improper response.  Try again.         "
          ?
          WAIT "Enter choice (a, b, or c): " TO CHAR
          CHAR = UPPER(CHAR)
     ENDDO
     IF CHAR="A"
          REPLACE SALUTE WITH "Mr."
     ENDIF
     IF CHAR="B"
          REPLACE SALUTE WITH "Ms."
     ENDIF
     IF CHAR="C"
          REPLACE SALUTE WITH "Mrs."
     ENDIF
     *
     CLEAR
     *
     @10,0 SAY ""
     ACCEPT "Enter monitor's first name:  " TO CHAR
     REPLACE FIRST_NAME WITH CHAR
     *
     @10,0 SAY ""
     ACCEPT "Enter monitor's last name:            " TO CHAR
     REPLACE LAST_NAME WITH CHAR
     CLEAR
     @12,5 SAY "Monitor's name is:  "
     @14,5 SAY TRIM(SALUTE)+" "+TRIM(FIRST_NAME)+" "
                    +LAST_NAME
     ?
     ?
     WAIT "Is this correct (y/n)?" TO CHAR
     IF UPPER(CHAR)="Y"
          OPT=.T.
     ENDIF
ENDDO
CLEAR MEMORY
*
CLEAR
@10,0 SAY " "
```

```
ACCEPT "Enter the building monitor's office symbol:  " TO
             CHAR
CHAR = UPPER(CHAR)
?
?
*******  Following loop checks entry  ***********
*
OPT = .F.
DO WHILE .NOT. OPT
     @17,0 SAY "Your entry was:  "+CHAR
     WAIT "Is this correct (y/n)?" TO CHOICE
     CHOICE = UPPER(CHOICE)
     IF CHOICE="Y"
          OPT = .T.
     ELSE
          @16,0 SAY "                                        "
          ACCEPT "Enter office symbol again:  " TO CHAR
          CHAR = UPPER(CHAR)
     ENDIF
ENDDO
REPLACE OFF_SYMBOL WITH CHAR
*
*
CLEAR
@10,0 SAY " "
ACCEPT "Enter the building monitor's phone number:  " TO
              CHAR
?
?
*******  Following loop checks entry  ***********
*
OPT = .F.
DO WHILE .NOT. OPT
     @17,0 SAY "Your entry was:  "+CHAR
     WAIT "Is this correct (y/n)?" TO CHOICE
     CHOICE = UPPER(CHOICE)
     IF CHOICE="Y"
          OPT = .T.
     ELSE
          @16,0 SAY "                                        "
          ACCEPT "Enter phone number again:  " TO CHAR
          CHAR = UPPER(CHAR)
     ENDIF
ENDDO
REPLACE PHONE WITH CHAR
*

CLEAR
@10,0 SAY "1.  Which of the following best describes this
building?"
```

```
@12,5 SAY "a.  Multi-unit building"
@13,5 SAY "b.  Single-unit building"
@14,5 SAY "c.  Mobile home"
@15,5 SAY "d.  Other"
?
?
?
WAIT "Enter choice (a, b, c, or d): " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="A" .OR. CHAR="B" .OR. CHAR="C" .OR.
                CHAR="D")
      @19,0 SAY "Improper response.  Try again.          "
      ?
      WAIT "Enter choice (a, b, c, or d): " TO CHAR
      CHAR = UPPER(CHAR)
ENDDO
REPLACE Q1 WITH CHAR
*
CLEAR
@10,0 SAY "2.  How many levels or stories does this building
have?"
@12,5 SAY "a.  Single story"
@13,5 SAY "b.  Split level"
@14,5 SAY "c.  Two-story"
@15,5 SAY "d.  3 or more stories"
?
?
?
WAIT "Enter choice (a, b, c, or d): " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="A" .OR. CHAR="B" .OR. CHAR="C" .OR.
                   CHAR="D")
      @19,0 SAY "Improper response.  Try again.            "
      ?
      WAIT "Enter choice (a, b, c, or d): " TO CHAR
      CHAR = UPPER(CHAR)
ENDDO
REPLACE Q2 WITH CHAR
*
CLEAR
@10,0 SAY "3.  Approximately how many square feet of floor
                     space is"
@11,5 SAY "there on the bottom story or basement?"
?
?
DO WHILE .NOT. UPPER(CHAR)="Y"
     INPUT "Enter size in sq. ft. and press Return:  " TO
                SIZE
     CLEAR
     @14,0 SAY "Building is "+STR(SIZE,7,0)+" sq. ft."
```

```
     ?
     ?
     WAIT "Is this correct (y/n)?" TO CHAR
ENDDO
REPLACE Q3 WITH SIZE
*
*
CLEAR
@10,0 SAY "4.  About how old is this building?"
?
?
CHAR = "n"
DO WHILE .NOT. UPPER(CHAR)="Y"
     INPUT "Enter age in years and press Return:  " TO SIZE
     CLEAR
     @14,0 SAY "Building is "+STR(SIZE,7,0)+" years old."
     ?
     ?
     WAIT "Is this correct (y/n)?" TO CHAR
ENDDO
REPLACE Q4 WITH SIZE
*
CHAR = ""
CLEAR
@10,0 SAY "5.  Does this building have a full or partial
                   basement,"
@11,5 SAY "a cellar, or a level which has one or more walls"
@12,5 SAY "partially or completely below ground level?"
@13,5 SAY "Such a level will be considered a basement."
?
WAIT "Enter y for yes, n for no:  " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="Y" .OR. CHAR="N")
     @15,0 SAY "Improper entry.                                  "
     ?
     WAIT "Enter y for yes, n for no:  " TO CHAR
ENDDO
IF UPPER(CHAR)="N"
     REPLACE Q5 WITH .F.
ELSE
     REPLACE Q5 WITH .T.
*
* The following questions, 6-11, are skipped if no basement *
*
     CLEAR
     @8,0 SAY "6.  What are the outside walls of the base
                   ment?"
     @9,5 SAY "a.  Concrete block or cinder block"
     @10,5 SAY "b.  Poured concrete"
     @11,5 SAY "c.  Stone and mortar"
```

```
@12,5 SAY "d.  Wood"
@13,5 SAY "e.  Brick or brick veneer"
@14,5 SAY "f.  Earth, dirt, clay, etc."
@15,5 SAY "g.  Other"
?
?
?
WAIT "Enter choice (a, b, c, d, e, f, or g): " TO CHAR
CHAR = UPPER(CHAR)
*
*****  Following loop checks entry for a to g.  *******
*
DO WHILE .NOT.(ASC(CHAR)>064 .AND. ASC(CHAR)<072)
     @18,0 SAY "Improper entry.
"
     WAIT "Enter choice (a, b, c, d, e, f, or g):  " TO
              CHAR
     CHAR = UPPER(CHAR)
ENDDO
REPLACE Q6 WITH CHAR
*
CLEAR
@6,0 SAY "7.  Describe the approximate percentage of
                each type"
@7,5 SAY "of treatment of the inside of the outer
              walls"
@8,5 SAY "of the basement:"
?
?
?
TTLPCT = 0
DO WHILE .NOT. TTLPCT=100
     INPUT "a.  % Untreated:  " TO PERA
     INPUT "b.  % Panelling without insulation:  " TO
                          PERB
     INPUT "c.  % Panelling with insulation:  " TO PERC
     INPUT "d.  % Paint:  " TO PERD
     INPUT "e.  % Sealant or airtight paint:  " TO PERE
     INPUT "f.  % Other:  " TO PERF
     TTLPCT = PERA+PERB+PERC+PERD+PERE+PERF
     IF .NOT.(TTLPCT = 100)
          @12,0 SAY "Total does not add to 100%.  Start
               over."
          ?"                                             "
          ?"                                             "
          ?"                                             "
          ?"                                             "
          ?"                                             "
          @12,0 SAY ""
     ENDIF
```

```
ENDDO
REPLACE Q7A WITH PERA
REPLACE Q7B WITH PERB
REPLACE Q7C WITH PERC
REPLACE Q7D WITH PERD
REPLACE Q7E WITH PERE
REPLACE Q7F WITH PERF
CLEAR MEMORY
*
CLEAR
@13,5 SAY "8.  Is any part of basement floor exposed
                   earth?"
?
?
WAIT "     Enter y for yes, n for no:  " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="Y" .OR. CHAR="N")
     @16,0 SAY "Improper entry.                          "
     ?
     WAIT "Enter y for yes, n for no:  " TO CHAR
ENDDO
IF UPPER(CHAR)="Y"
     REPLACE Q8 WITH .T.
ELSE
     REPLACE Q8 WITH .F.
ENDIF
*
CLEAR
@13,0 SAY "9.  Are the any unsealed passages between
                    the"
@14,5 SAY "basement or crawl space and interior of
                    building?"
?
?
WAIT "     Enter y for yes, n for no:  " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="Y" .OR. CHAR="N")
     @17,0 SAY "Improper entry.                          "
     ?
     WAIT "Enter y for yes, n for no:  " TO CHAR
ENDDO
IF UPPER(CHAR)="Y"
     REPLACE Q9 WITH .T.
ELSE
     REPLACE Q9 WITH .F.
ENDIF
*
CLEAR
*
@13,0 SAY "10.  Is the primary heating system in the
```

```
                                  basement"
          @14,5 SAY "or crawl space?"
          ?
          ?
          WAIT "     Enter y for yes, n for no:  " TO CHAR
          CHAR = UPPER(CHAR)
          DO WHILE .NOT.(CHAR="Y" .OR. CHAR="N")
               @17,0 SAY "Improper entry.                              "
               ?
               WAIT "Enter y for yes, n for no:  " TO CHAR
          ENDDO
          IF UPPER(CHAR)="Y"
               REPLACE Q10 WITH .T.
          ELSE
               REPLACE Q10 WITH .F.
          ENDIF
          *
          CLEAR
          @13,0 SAY "11.  Is there a sump pump in the main drain"
          @14,5 SAY "for the basement or crawl space?"
          ?
          ?
          WAIT "     Enter y for yes, n for no:  " TO CHAR
          CHAR = UPPER(CHAR)
          DO WHILE .NOT.(CHAR="Y" .OR. CHAR="N")
               @17,0 SAY "Improper entry.                              "
               ?
               WAIT "Enter y for yes, n for no:  " TO CHAR
          ENDDO
          IF UPPER(CHAR)="Y"
               REPLACE Q11 WITH .T.
          ELSE
               REPLACE Q11 WITH .F.
          ENDIF
     ENDIF
     *
     CLEAR
     @10,0 SAY "12.  What percentage of the building is over
                         a..."
     ?
     ?
     ?
     TTLPCT = 0
     DO WHILE .NOT. TTLPCT=100
          INPUT "a.  % Over a Basement:  " TO PERA
          INPUT "b.  % Over a Concrete Slab:  " TO PERB
          INPUT "c.  % Over a Crawl Space:  " TO PERC
          INPUT "d.  % Over Open Air:  " TO PERD
          INPUT "e.  % Over Something Else:  " TO PERE
          TTLPCT = PERA+PERB+PERC+PERD+PERE
```

```
     IF .NOT.(TTLPCT = 100)
          @15,0 SAY "Total does not add to 100%.  Start
                         over."
          ?"                                          "
          ?"                                          "
          ?"                                          "
          ?"                                          "
          @16,0 SAY ""
     ENDIF
ENDDO
REPLACE Q12A WITH PERA
REPLACE Q12B WITH PERB
REPLACE Q12C WITH PERC
REPLACE Q12D WITH PERD
REPLACE Q12E WITH PERE
CLEAR MEMORY
CLEAR
*
@8,0 SAY "13.  List any other concrete or asphalt surfaces"
@9,5 SAY "attached to or bordering the foundation:"
@10,5 SAY "a.  None"
@11,5 SAY "b.  Driveway"
@12,5 SAY "c.  Parking structure or carport"
@13,5 SAY "d.  Patio"
@14,5 SAY "e.  Loading ramp"
@15,5 SAY "f.  Other"
?
ACCEPT "Enter choice (a, or combination of b, c, d, e, f): "
TO CHAR
CHAR = UPPER(CHAR)
*******  Following loop checks entry for a to f.  *********
*
OPT = .F.
DO WHILE .NOT. OPT
     @17,0 SAY "
     "
     @17,0 SAY "Your entry was:  "+CHAR
     WAIT "Is this correct (y/n)?" TO CHOICE
     CHOICE = UPPER(CHOICE)
     IF CHOICE="Y"
          OPT = .T.
     ELSE
          @16,0 SAY "                                    "
          ACCEPT "Enter  a, or any of b, c, d, e, f): " TO
                      CHAR
          CHAR = UPPER(CHAR)
     ENDIF
ENDDO
REPLACE Q13 WITH CHAR
*
```

```
CLEAR
@10,0 SAY "14.  What type of distribution system is used"
@11,5 SAY "for primary heat?"
@13,5 SAY "a.  Forced air"
@14,5 SAY "b.  Hot water or steam (radiator, baseboard)"
@15,5 SAY "c.  Natural convection (fireplace, woodstove,
                  etc.)"
@16,5 SAY "d.  Other"
?
?
?
WAIT "Enter choice (a, b, c, or d): " TO CHAR
CHAR = UPPER(CHAR)
*
******  Following loop checks entry for a to d.  ***********
*
DO WHILE .NOT.(ASC(CHAR)>064 .AND. ASC(CHAR)<069)
     @20,0 SAY "Improper entry.
"
     WAIT "Enter choice (a, b, c, or d):  " TO CHAR
     CHAR = UPPER(CHAR)
ENDDO
REPLACE Q14 WITH CHAR
*
CLEAR

@06,0 SAY "15.  What fuel is used for primary heating?"
@08,5 SAY "a.  Natural gas"
@09,5 SAY "b.  Electricity"
@10,5 SAY "c.  Oil"
@11,5 SAY "d.  Coal"
@12,5 SAY "e.  Propane or bottled gas"
@13,5 SAY "f.  External Steam Source"
@14,5 SAY "g.  Wood"
@15,5 SAY "h.  Other"
?
?
WAIT "Enter choice (a, b, c, d, e, f, g, or h): " TO CHAR
CHAR = UPPER(CHAR)
*
******  Following loop checks entry for a to h.  ***********
*
DO WHILE .NOT.(ASC(CHAR)>064 .AND. ASC(CHAR)<073)
     @18,0 SAY "Improper entry.                          "
     WAIT "Enter choice (a, b, c, d, e, f, g, or h):  " TO
                CHAR
     CHAR = UPPER(CHAR)
ENDDO
REPLACE Q15 WITH CHAR
FLAG=.F.
```

```
*** Following statement checks for combustion. *
*** If true, skip question #17 *
IF CHAR="B" .OR. CHAR="F"
     FLAG=.T.
ENDIF
*
CLEAR
@10,0 SAY "16.  Is any part of this building excluding the
                       basement"
@11,5 SAY "built on a concrete slab?"
?
?
WAIT "      Enter y for yes, n for no:  " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="Y" .OR. CHAR="N")
     @14,0 SAY "Improper entry.                              "
     ?
     WAIT "Enter y for yes, n for no:  " TO CHAR
ENDDO
IF UPPER(CHAR)="Y"
     REPLACE Q16 WITH .T.
ELSE
     REPLACE Q16 WITH .F.
ENDIF
*
CLEAR
IF .NOT. FLAG
     @10,0 SAY "17.  If the primary heat source is some
                      kind"
     @11,5 SAY "of combustion, is outside air brought in to
                      replace"
     @12,5 SAY "the exhaust going up through the chimney?"
     ?
     ?
     WAIT "      Enter y for yes, n for no:  " TO CHAR
     CHAR = UPPER(CHAR)
     DO WHILE .NOT.(CHAR="Y" .OR. CHAR="N")
          @15,0 SAY "Improper entry.                              "
          ?
          WAIT "Enter y for yes, n for no:  " TO CHAR
     ENDDO
     IF UPPER(CHAR)="Y"
          REPLACE Q17 WITH .T.
     ELSE
          REPLACE Q17 WITH .F.
     ENDIF
     *
     CLEAR
ENDIF
*
```

```
@10,0 SAY "18.  Is there an air-to-air heat exchanger or"
@11,5 SAY "heat-recovery ventilator in this building?"
?
?
WAIT "     Enter y for yes, n for no:  " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="Y" .OR. CHAR="N")
     @14,0 SAY "Improper entry.                          "
     ?
     WAIT "Enter y for yes, n for no:  " TO CHAR
ENDDO
IF UPPER(CHAR)="Y"
     REPLACE Q18 WITH .T.
ELSE
     REPLACE Q18 WITH .F.
ENDIF
*
CLEAR
@10,0 SAY "19.  Does this building use the base water
                 supply,"
@11,5 SAY "or is the water drawn from a private well?"
@13,5 SAY "a.  Base or public water supply"
@14,5 SAY "b.  Private well"
?
?
?
WAIT "Enter choice (a or b): " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="A" .OR. CHAR="B")
      @19,0 SAY "Improper response.  Try again.          "
      ?
      WAIT "Enter choice (a or b): " TO CHAR
      CHAR = UPPER(CHAR)
ENDDO
REPLACE Q19 WITH CHAR
*
CLEAR
@6,0 SAY "20.  Does the building have any of the following
                      gas"
@7,5 SAY "or propane fueled appliances?"
@9,5 SAY "a.  Water heater"
@10,5 SAY "b.  Clothes dryer"
@11,5 SAY "c.  Stove/Oven"
@12,5 SAY "d.  Refrigerator"
@13,5 SAY "e.  Air conditioner"
@14,5 SAY "f.  Heat pump"
@15,5 SAY "g.  Fork Lift"
@16,5 SAY "h.  Other"
?
ACCEPT "Enter choice (any/all of a, b, c, d, e, f, g, h): " TO
```

```
CHAR
CHAR = UPPER(CHAR)
*******  Following loop checks entry   ***********
*
OPT = .F.
DO WHILE .NOT. OPT
     @19,0 SAY "Your entry was:  "+CHAR
     WAIT "Is this correct (y/n)?" TO CHOICE
     CHOICE = UPPER(CHOICE)
     IF CHOICE="Y"
          OPT = .T.
     ELSE
          @16,0 SAY "                                          "
          ACCEPT "Enter  a, or any of b, c, d, e, f): " TO
                       CHAR
          CHAR = UPPER(CHAR)
     ENDIF
ENDDO
REPLACE Q20 WITH CHAR
*
CLEAR
@10,0 SAY "21.  Does this building have central air
                  conditioning?"
?
?
WAIT "     Enter y for yes, n for no:  " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="Y" .OR. CHAR="N")
     @13,0 SAY "Improper entry.                       "
     ?
     WAIT "Enter y for yes, n for no:  " TO CHAR
     CHAR=UPPER(CHAR)
ENDDO
IF UPPER(CHAR)="Y"
     REPLACE Q21 WITH .T.
ELSE
     REPLACE Q21 WITH .F.
ENDIF
*
CLEAR
@10,0 SAY "22.  Does this building have any of these other
                     A/C"
@10,54 SAY "systems?"
@12,5 SAY "a.  Window or wall-mounted units"
@13,5 SAY "b.  Swamp or evaporative coolers"
@14,5 SAY "c.  None"
?
?
?
WAIT "Enter choice (a, b, or c): " TO CHAR
```

```
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="A" .OR. CHAR="B" .OR. CHAR="C")
      @19,0 SAY "Improper response.  Try again.                 "
      ?
      WAIT "Enter choice (a, b, or c): " TO CHAR
      CHAR = UPPER(CHAR)
ENDDO
REPLACE Q22 WITH CHAR
*
CLEAR
@10,0 SAY "23.  Does the building have an exhaust fan"
@11,5 SAY "which blows air outside?"
?
?
WAIT "     Enter y for yes, n for no:  " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="Y" .OR. CHAR="N")
     @14,0 SAY "Improper entry.                          "
     ?
     WAIT "Enter y for yes, n for no:  " TO CHAR
ENDDO
IF UPPER(CHAR)="N"
     REPLACE Q23 WITH .F.
ELSE
     REPLACE Q23 WITH .T.
     CLEAR
     @10,0 SAY "24.  How often is the exhaust fan used"
     @11,5 SAY "during the cooling season?"
     @13,5 SAY "a.  Every day"
     @14,5 SAY "b.  Not daily, but more than once a week"
     @15,5 SAY "c.  Regularly, but less than once a week"
     @16,5 SAY "d.  Seldom or never"
     ?
     ?
     ?
     WAIT "Enter choice (a, b, c, or d): " TO CHAR
     CHAR = UPPER(CHAR)
     DO WHILE .NOT.(ASC(CHAR)>64 .AND. ASC(CHAR)<69)
           @20,0 SAY "Improper response.  Try again.       "
           ?
           WAIT "Enter choice (a, b, c, or d): " TO CHAR
           CHAR = UPPER(CHAR)
     ENDDO
     REPLACE Q24 WITH CHAR
ENDIF
*
CLEAR
@10,0 SAY "25.  Overall, how tightly sealed is this
                    building?"
@12,5 SAY "a.  Tightly"
```

```
@13,5 SAY "b.  Moderately"
@14,5 SAY "c.  Leaky"
@15,5 SAY "d.  Don't know"
?
?
?
WAIT "Enter choice (a, b, c, or d): " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="A" .OR. CHAR="B" .OR. CHAR="C" .OR.
                     CHAR="D")
      @19,0 SAY "Improper response.  Try again.            "
      ?
      WAIT "Enter choice (a, b, or c): " TO CHAR
      CHAR = UPPER(CHAR)
ENDDO
REPLACE Q25 WITH CHAR
*
CLEAR
@10,0 SAY "26.  Considering both heating and cooling
                     seasons,"
@11,5 SAY "about how many months of the year is the
                     building"
@12,5 SAY "sealed up, that is, windows and doors usually
                     closed?"
?
?
DO WHILE .NOT. UPPER(CHAR)="Y"
     INPUT "Enter number of months and press Return:  " TO
               SIZE
     CLEAR
     @15,0 SAY "Entry is "+STR(SIZE,2,0)+" months"
     ?
     ?
     WAIT "Is this correct (y/n)?" TO CHAR
ENDDO
REPLACE Q26 WITH SIZE
*
RETURN


*****************  ADDVIAL.PRG  ********************
*** PROGRAM TO ADD NEW VIAL DATA TO BASERAD.DBF  *****
SET TALK OFF
SET ECHO OFF
USE BASERAD
*
CLEAR
@10,0 SAY "Which building was the vial exposed in?"
?
ACCEPT "Enter the building's number:  " TO BLDGNUM
```

```
BLDGNUM = UPPER(BLDGNUM)
CLEAR
@10,0 SAY "What area is this building in?"
?
?
WAIT "Enter A, B, C, or Kittyhawk (K):  " TO CHAR
CHAR = UPPER(CHAR)
DO WHILE .NOT.(CHAR="A" .OR. CHAR="B" .OR. CHAR="C" .OR.
                      CHAR="K")
     @13,0 SAY "Improper entry.  Try again.          "
     WAIT "Enter A, B, C, or Kittyhawk (K):  " TO CHAR
     CHAR=UPPER(CHAR)
ENDDO
CLEAR
*
CLEAR
@10,0 SAY "Enter the date vial was closed, that is, "
ACCEPT "the end of exposure (MM/DD/YY):  " TO DEXP
*
CLEAR
@10,0 SAY ""
ACCEPT "How many hours was the vial open?  " TO HOURS
*
OPT=.T.
*
DO WHILE OPT
     CLEAR
     @10,0 SAY ""
     ACCEPT "Enter the new vial's serial number:  " TO
              SERIAL
     KOUNT = 0
     COUNT FOR SERIAL_NUM=SERIAL TO KOUNT
     IF KOUNT>0
         ?
         ?
         ?"              Vial is already in database!"
         ?"              Use Task Code 4 to edit it."
         ?
         WAIT"              Press any key to continue...."
         RETURN
     ENDIF
     *
     APPEND BLANK
     REPLACE SERIAL_NUM WITH SERIAL
     REPLACE BUILDING WITH BLDGNUM
     REPLACE AREA WITH CHAR
     REPLACE EXP_DATE WITH CTOD(DEXP)
     REPLACE EXP_TIME WITH VAL(HOURS)
     CLEAR
     @3,50 SAY "Vial S/N:  "+SERIAL
```

```
    @7,0 SAY "Describe, in 20 characters or less, the
                  location"
    @8,5 SAY "of the vial during exposure.  Be sure to
                  include"
    @9,5 SAY "the floor level, and note any details such
                  as"
    @10,5 SAY "near sump, in office, bedroom, etc."
    ?
    ACCEPT "Enter description:  " TO DESC
    REPLACE LOCATION WITH DESC
    *
    CLEAR
    @3,50 SAY "Vial S/N:  "+SERIAL
    @10,0 SAY "How many grams did the vial weigh before
                     exposure? "
    SET DECIMALS TO 4
    INPUT TO PREWGT
    @15,0 SAY "And how much did it weigh after exposure?  "
    INPUT TO POSTWGT
    REPLACE PRE_WGT WITH PREWGT
    REPLACE POST_WGT WITH POSTWGT
    REPLACE WGT_GAIN WITH POSTWGT-PREWGT
    *
    CLEAR
    @3,50 SAY "Vial S/N:  "+SERIAL
    @10,0 SAY ""
    INPUT "What count rate did the computer report?  " TO
              CNTRT
    ?
    ?
    INPUT "And what was the 2 sigma error in percent?  " TO
              ERROR
    REPLACE CPM WITH CNTRT
    REPLACE CPM_SIG WITH ERROR/2
    DO CALC_CONC
    @20,0 SAY "The concentration of radon at this location
              is"
    ?STR(RADON_CONC,7,2)+" pCi/li+/-"
              +TRIM(STR(CONC_SIGM,7,2))+"%"
    WAIT
    CLEAR
    @3,50 SAY "Vial S/N:  "+SERIAL
    @10,0 SAY "Is there another vial which was exposed in
              the"
    WAIT "same building on the same day (y/n)?  " TO DESC
    IF .NOT. UPPER(DESC) = "Y"
          OPT = .F.
    ENDIF
ENDDO
CLEAR MEMORY
```

```
CLEAR
RETURN


******************  EDTBLDG.PRG  *******************
*** PROGRAM TO EDIT A BUILDING IN BASBLDGS.DBF  ****
SET TALK OFF
SET ECHO OFF
USE BASBLDGS
ACCEPT "Enter the building's number: " TO BLDGNUM
COUNT TO KOUNT
COUNT FOR BLDG_NUMB=BLDGNUM
IF KOUNT=0
    ?
    ?
    ?"          Building is not in database!"
    ?"          Use Task Code 1 to add it."
    ?
    WAIT"          Press any key to continue...."
    RETURN
ENDIF
*
LOCATE FOR BLDG_NUMB = BLDGNUM
EDIT
RETURN


******************  EDTVIAL.PRG  *******************
*** PROGRAM TO EDIT A VIAL IN BASERAD.DBF  ****
SET TALK OFF
SET ECHO OFF
USE BASERAD
ACCEPT "Enter the vial's serial number: " TO SERIAL
COUNT TO KOUNT
COUNT FOR SERIAL_NUM=SERIAL
IF KOUNT=0
    ?
    ?
    ?"          This vial is not in the database!"
    ?"          Use Task Code 2 to add it."
    ?
    WAIT"          Press any key to continue...."
    RETURN
ENDIF
*
LOCATE FOR SERIAL_NUM = SERIAL
CLEAR
@5,5 SAY "Do you wish to edit the count rate and/or
            uncertainty?"
?
```

```
WAIT "Enter y if so, anything else if not:  " TO CHAR
IF UPPER(CHAR) = "Y"
    CLEAR
    @5,5 SAY "Present count rate is:  "+STR(CPM,8,2)+"cpm."
    ?
    CHAR = "N"
    WAIT "Enter Y if you wish to change it:  " TO CHAR
    IF UPPER(CHAR)="Y"
        ?
        INPUT "Enter new counts per minute:  " TO RATE
        REPLACE CPM WITH RATE
    ENDIF
    CLEAR
    @5,5 SAY "Present uncertainty is:  "
                           +STR(CPM_SIG,8,2)+"%"
    ?
    CHAR = "N"
    WAIT "Enter Y if you wish to change it:  " TO CHAR
    IF UPPER(CHAR)="Y"
        ?
        INPUT "Enter new uncertainty (2 sigma, %):  " TO
                   RATE
        REPLACE CPM_SIG WITH RATE/2
    ENDIF
    CLEAR
ELSE
    EDIT
ENDIF
DO CALC_CONC
RETURN


******************  DLTBLDG.PRG  ********************
*** PROGRAM TO DELETE A BUILDING FROM BASBLDGS.DBF  ****
SET TALK OFF
SET ECHO OFF
USE BASBLDGS
ACCEPT "Enter the building's number: " TO BLDGNUM
COUNT TO KOUNT
COUNT FOR BLDG_NUMB=BLDGNUM
IF KOUNT=0
    ?
    ?
    ?"          Building is not in database!"
    ?"          Use Task Code 1 to add it."
    ?
    WAIT"             Press any key to continue...."
    RETURN
ENDIF
*
```

```
GO TOP
WAIT"Are you sure you want to delete this building from the
                  database? " TO SURE
IF UPPER(SURE)="Y"
    DELETE FOR BLDG_NUMB=BLDGNUM .AND. BLDGNUM=BLDG_NUMB
    PACK
    ?"The building has been deleted."
    ?
    WAIT"Would you also like to delete all the vials which
         measured the radon levels in this building? " TO
                  SURE
    IF UPPER(SURE)="Y"
        USE BASERAD
        GO TOP
        DELETE FOR BLDG_NUMB=BLDGNUM .AND. BLDGNUM=BLDG_NUMB
        PACK
        ?"All vials have been deleted."
    ENDIF
ENDIF
RETURN


******************  DLTVIAL.PRG  ********************
*** PROGRAM TO DELETE A VIAL FROM BASERAD.DBF  ******
SET TALK OFF
SET ECHO OFF
USE BASERAD
ACCEPT "Enter the vial's serial number: " TO SERIAL
COUNT TO KOUNT
COUNT FOR SERIAL_NUM=SERIAL
IF KOUNT=0
    ?
    ?
    ?"          The vial is not in the database!"
    ?
    WAIT"             Press any key to continue...."
    RETURN
ENDIF
*
GO TOP
WAIT"Are you sure you want to delete this vial from the i
                           database? " TO SURE
IF UPPER(SURE)="Y"
    DELETE FOR SERIAL_NUM=SERIAL
    PACK
    ?"The vial has been deleted."
    ?
ENDIF
RETURN
```

```
***** Program genrply to generate a reply ******
***** to send to building monitor on WPAFB *****
***** with results of radon testing ************
*
SET TALK OFF
SET ECHO OFF
*** Following lines set up both databases needed; ****
*** SELECT 1 will select BASERAD.DBF, ***************
*** SELECT 2 will select BASBLDGS.DBF  ***************
*
SELECT 1
USE BASERAD
SELECT 2
USE BASBLDGS
*
*  Following lines check to see if building is already *
*  in the database, exits if not, reports if so.       *
KOUNT = 0
CLEAR
@10,0 SAY ""
ACCEPT "Enter the new building's number: " TO BLDGNUM
COUNT FOR BLDG_NUMB=BLDGNUM TO KOUNT
IF .NOT. KOUNT>0
    ?
    ?
    ?"            Building is not in database!"
    ?"            Use Task Code 1 to add it."
    ?
    WAIT"             Press any key to continue...."
    RETURN
ENDIF
SELECT 1
COUNT FOR BUILDING=BLDGNUM TO KOUNT
IF .NOT. KOUNT>0
    ?
    ?
    ?"            Building has no vials in database!"
    ?"            Use Task Code 2 to add some."
    ?
    WAIT"             Press any key to continue...."
    RETURN
ENDIF
*
** Building has vials in database **************
** Begin generating report *********************
*
SET PRINT ON
SET DEVICE TO PRINT
```

```
SELECT 2
GO TOP
LOCATE FOR BLDG_NUMB=BLDGNUM
@5,50 SAY DATE()
?
? TRIM(SALUTE)+" "+TRIM(FIRST_NAME)+" "+TRIM(LAST_NAME)
? TRIM(OFF_SYMBOL)+", Building "+TRIM(BLDGNUM)
@10,0 SAY "William D. Pierce"
@11,0 SAY "AFIT/GEP90D Box 4499"
*
@14,0 SAY TRIM(SALUTE)+" "+TRIM(LAST_NAME)+":"
TEXT

     Here are the results from the recent evaluation of radon
concentrations in your building:
ENDTEXT
SELECT 1
SET FILTER TO BUILDING=BLDGNUM .AND. BLDGNUM=TRIM(BUILDING)
*  Following lines find largest concentration found.  *
GO TOP
BIG = 0.0
DO WHILE .NOT. EOF()
    IF BIG<=RADON_CONC
        BIG=RADON_CONC
    ENDIF
    SKIP
ENDDO
*  Output results from all vials. *
GO TOP
?
REPORT FORM RADCONC TO PRINT
?
GO TOP
LOCATE FOR BIG=RADON_CONC
LOW = 4 * (1.0-CONC_SIGM/100)
HIGH = 4
*  Following section changes output based upon    *
*  whether concentrations were above EPA's action level.  *
DO CASE
*
    CASE BIG<=LOW
        TEXT
     None of the samples of your building demonstrated radon
levels above the EPA's action level of 4 pCi/li.
        ENDTEXT
*
    CASE LOW < BIG .AND.  BIG < HIGH
        TEXT
     At least one of the samples from your building demon-
strated a radon concentration near the EPA's action of 4
```

```
pCi/li.  This level is set by EPA for areas occupied at least
75% of the time.
        ENDTEXT
*
    CASE BIG >= HIGH
        TEXT
     The EPA has set a maximum radon concentration of 4 pCi/li
for any building which is occupied 75% of the time.  At least
one of the samples taken in your building read higher.  Any
concentration above 4 pCi/li is cause for concern only if it
is found in a work area or living space; however, it can serve
to point out possible sources of radon.
        ENDTEXT
*
ENDCASE
TEXT
     Please keep in mind that this is only a preliminary test;
radon levels vary with time of day and especially over the
year.  No action should be taken on any results given here.
If your building measured above the EPA's minimum in a working
or living area, it is recommended that you have additional
testing done, including an average reading over an entire
year.
     Thank you for participating in this survey and so helping
me out on my master's thesis.  If you have any questions or
comments please contact me or my advisor, Dr. George John,
AFIT/GNE, 5-4498.
     A copy of this report is also being sent to Gary Lindsey
in the environmental management office, who is heading up the
base Radon Assessment and Mitigation Program.

                                                 Sincerely,



                                                 William D. Pierce
                                                 AFIT/GEP-90D

ENDTEXT
SET DEVICE TO SCREEN
SET PRINT OFF
CLEAR MEMORY
RETURN




*  Program calc_conc.prg  *
*  This program calculates the radon concentration and *
```

```
*  the uncertainty from the entered values of      *
*  count rate and sigma.  Values were obtained     *
*  from Capt. Sharp's thesis.                      *
DO CASE
    CASE  12 <= EXP_TIME .AND. EXP_TIME < 20
        FAC = 0.0357
        SIGFAC = 0.3
    CASE  20 <= EXP_TIME .AND. EXP_TIME < 28
        FAC = 0.0305
        SIGFAC = 0.9
    CASE  28 <= EXP_TIME .AND. EXP_TIME < 39
        FAC = 0.028
        SIGFAC = 7
    CASE  39 <= EXP_TIME .AND. EXP_TIME < 60
        FAC = 0.02605
        SIGFAC = 1.9
    CASE  60 <= EXP_TIME .AND. EXP_TIME < 90
        FAC = 0.0273
        SIGFAC = 9.3
    OTHERWISE
        CLEAR
        @10,5 SAY "WARNING!  No conversion factor exists for
                       the"
        @12,5 SAY "exposure time for this vial.  You must
                       figure"
        @14,5 SAY "out the radon concentration and uncer
                       tainty"
        @16,5 SAY "and enter them by hand!"
        RETURN
ENDCASE
REPLACE RADON_CONC WITH CPM*FAC
REPLACE CONC_SIGM WITH 5.0 + SQRT(SIGFAC^2 + CPM_SIG^2)
RETURN
```

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Vita

William David Pierce was born on March 11, 1959, in Detroit, Michigan. He graduated from Stevenson Senior High School in June of 1977 as a National Merit Scholar. Half of his Junior year in college was spent as an exchange student at the University of Bonn in West Germany. In June of 1981 he received a Bachelor of Arts degree in Physics from Kalamazoo College in Kalamazoo, Michigan. The US Air Force accepted him into the Fast Track program at the University of Dayton, where he received a Bachelor's degree in Electronics Engineering in May, 1984. Upon graduation he began working for AFLC at Hill AFB, Utah, as a software engineer. His responsibilities include verification, validation, and maintenance of automatic test equipment software for F-16 avionics. In May, 1989, he enrolled into the Air Force Institute of Technology as a master's candidate in Engineering Physics.

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